THE LIGHTING ART

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THE LIGHTING ART

ITS PRACTICE AND POSSIBILITIES

BY

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Dedicated to

THE RELATIVELY SMALL GROUP OF MEN WHOSE UNSELFISH EFFORTS IN LIGHTING ARE DIRECTED TOWARD THE CONSERVATION OF VISION —THAT MOST VALUABLE HUMAN RESOURCE—AND TOWARD THE INCREASE IN THE SAFETY, THE EFFICIENCY, AND THE PLEASURE OF MANKIND THROUGH THE APPLICATIONS OF LIGHT—THAT MOST POTENT NATURAL AGENCY.

PREFACE

Mankind has enjoyed such an abundance of natural daylight throughout the entire existence and evolution of the human race that the present general indifference to the possibilities in lighting is easily accounted for. With the advent of artificial light-sources of greater adaptability, the activities of man changed considerably and as modern artificial illuminants are readily controllable there naturally has arisen a new science and art, namely, that of lighting. Such desirable features as adaptability and controllability often result in misuses of artificial light at the hands of those who are indifferent to or untrained in the proper use of light. This together with the greatly increased possibilities led to the development of specialists in lighting and, owing to his connection with many of the activities upon which the production of light depends, the engineer became the embryo from which the so-called illuminating engineer of today evolved.

As the efficiency and adaptability of artificial light-sources and the knowledge of the importance of proper lighting developed, the demands upon the engineer became more varied until today when the many aspects and possibilities are becoming more appreciated, the engineer must greatly extend his horizon and knowledge in order to qualify as a lighting specialist in the broadest sense. Notwithstanding the extensive possibilities in lighting at the present time and the myriad ramifications of the attendant problems into various sciences and arts, there is still a tendency on the part of many to look upon a lighting problem primarily from the engineering standpoint regardless of the nature of the problem.

Bearing witness to this fact are the books on lighting which consist largely of engineering data and considerations. A vast amount of lighting which has been well done, has been accomplished through applications of scientific and artistic principles not covered by engineering data. However, the latter are of

great value and there is no intention on my part to depreciate their value. These data have a definite place in lighting and they have aided to no small degree in the development of lighting practice. But in practising lighting from the engineer's viewpoint dominantly and persistently, the results are naturally those of illuminating engineering. However if lighting be practised from that broader viewpoint of the lighting specialist who has become familiar with the sciences and arts into which the problems lead, the results will be more worthy of the potentiality of light.

The purpose of this book is to discuss lighting broadly from an unusual viewpoint. Engineering and scientific data may be found elsewhere in great abundance so that the following chapters will be confined to discussions of many scientific and artistic aspects of lighting with the aim to indicate greater possibilities in the use of light. Believing that discussions of principles aid in cultivating creative ability I have given unusual prominence to this aspect of lighting.

It is a pleasant duty to acknowledge my gratitude to the management of the National Lamp Works of the General Electric Company for the facilities which I have enjoyed in the study of lighting and to Dr. E. P. Hyde, Director of Nela Research Laboratory, for placing these facilities at my disposal.

M. LUCKIESH.

October, 1917.

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ITS PRACTICE AND POSSIBILITIES

CHAPTER I

THE BROAD ASPECT OF LIGHTING

Light is one of the dominating agencies in life and progress, for it is essential to our most important and educative sense—vision. The possibilities of lighting extend into all those activities which make their appeal to human consciousness through the doorway of vision. The importance of lighting is limited only by the boundaries of human activities and in the broadest sense its importance extends even beyond them, for it is one of the most prominent factors in the scheme of creation. The activities of primitive man were practically bounded by sunrise and sunset, and darkness was feared and avoided as the abode of evil spirits and of lurking dangers. We may imagine a growing desire for independence which resulted in the making of fire by those primitive beings. Doubtless light was merely a by-product of the fire whose primary function was to furnish heat; nevertheless we may imagine primitive man with his burning pine knot exultant in his victory over Nature. This achievement was one of the first important milestones on the highway of human progress. Man's activities were no longer limited to daylight hours and greater opportunities were before him.

We inherit the primitive instincts of the impressiveness of light, color and darkness and this heritage combined with the cultivation of the esthetic sense provides a vast field of appeal for lighting effects properly tuned to awaken the responsive chords. In a broad sense lighting has potential possibilities in connection with all the arts, such as decoration, painting, sculpture, and architecture which employ light, shade, and

color. But lighting possesses a potentiality exceeding the media employed in such arts for it deals with "primary" light whose expressive and imitative possibilities are limited only by the capacity of the sense of vision. The media employed in the arts strive to imitate light but their ranges are bounded by the extreme limitations of transmitting and reflecting media. This aspect of lighting is perhaps the least developed of any of the many phases of possibilities because lighting-artists have barely entered the field. Nevertheless, it appears that in expressiveness and impressiveness in lighting lies one of the greatest fields for future development.

Returning to the purely utilitarian aspect of lighting we find unnumbered centuries elapsed between the first burning fagot and the advent of the grease lamp and the wax candle. Then the tallow candle appeared and its use extends to the present time—a connecting link to the period when practicable artificial light-sources were first available. From this retrospective view springs the realization that artificial lighting worthy of the name is a development of a comparatively modern period. In reality it is difficult to note the place where science entered the field of light-production. In a sense it has always been present for that which changes the mysteries of today into commonplace facts of tomorrow is science, in whatever guise.

However, as we look backward, science as we define it today really attacked the problem of light-production in an organized manner not many years ago. The results which followed in rapid succession yielded the oil lamp, gas jets and mantles. Reinforced by electrical development, science gave to the world the arcs and incandescent lamps. With an ever-increasing momentum these lamps were improved, new materials were discovered, and better manufacturing processes were developed with the result that in the last 25 years remarkable progress has been made in light production.

When it is noted that the remarkable industrial progress of the past century is coincident with the great progress in light-production one cannot avoid the conclusion that this is not merely a coincidence. Perhaps a future superhuman stat-

istician will be able to look back upon these two parallel lines of progress and credit lighting with no small responsibility in the momentous industrial development of the present age. Man now pursues his activities wherever he desires quite independent of daylight. Industries continue 24 hours per day which at least doubles the production of an equipment previously dependent upon natural lighting. In crowded smoky cities artificial light is often depended upon entirely. New arts have developed with the advent of effective artificial lighting and our living conditions have been so altered that artificial lighting is a very essential factor. Incidentally, a vast number of persons find little time to recreate and to cultivate the intellect except with the aid of artificial lighting, which suggests economic and even sociological aspects worthy of consideration.

Owing to changed conditions of working even natural daylight may no longer be considered to be free from cost when admitted into those interiors where industrial and commercial activities are pursued. From an architectural standpoint natural daylighting must bear a certain investment and maintenance cost. In our crowded cities natural lighting must be charged with no inappreciable amount for the floor and wall area sacrificed, and in various minor ways the cost of natural daylight indoors increases. Although no figures are available it appears reasonable to conclude, on bringing into consideration the element of satisfactoriness that there are many places where artificial lighting may compete with natural lighting on the basis of cost. This is an aspect worthy of future consideration. At present the psychological effect of excluding daylight would develop opposition to such a proposal but night-workers and many day-workers are content without it if the artificial lighting is reasonably satisfactory. With the ever-increasing congestion, the cost of floor and wall space, and the necessity for the most efficient operation of industrial and commercial plants, the cost of daylight will be given more attention. Aspects such as ventilation and the hygienic influence of sunlight will doubtless be met by science and it is not unreasonable to suggest a greater independence from daylight in the future.

But with the increasing demands upon artificial lighting and

with the development of light-sources of higher efficiency, which has been attended usually by more powerful light-sources of higher intrinsic brightnesses, dangers of misuses of light arose. As we look back at any of the early practicable artificial illuminants of the past century we might sincerely feel,

> " 'Twas a light that made
> Darkness itself appear
> A thing of comfort,"

owing to the feeble efforts which those illuminants were capable of exerting against the ever-crowding darkness. Today the same sentiment is appropriate but for an opposite reason. As we look about us at the powerful exposed light-sources of high intrinsic brightness, the severe contrasts of brightness, the bad positions of the lighting units, the harsh shadows, and the absence of artistic results we may readily subscribe to the same sentiment. In the first case those words were quoted through pity but in the last case through anguish, physical and mental. Thus in our imagination, as we traverse only a part of a century, we find ourselves in this brief period first extending sympathy to the feeble light-sources in their battle against darkness which threatened to overwhelm them and shortly the tables are turned and we find ourselves begging for relief against powerful glaring light-sources.

The foregoing picture is correct in its general features but unfortunately it is unnoticed by a vast majority of persons whose eyesight, disposition, efficiency and safety are constantly being jeopardized. Throughout his entire evolution, man has been supplied with an abundance of natural daylight and, after momentarily exulting when he discovered a process of making fire and simultaneously of producing artificial light, he again relapsed into that placid indifference toward lighting which persists among a vast majority of persons even today. This indifference is one of the chief obstacles in the way of lighting progress. A comparatively small number of persons, whose activities brought them especially in touch with the harmful effects of bad lighting and with the great possibilities of proper lighting, has set about to protect the eyesight

of the race and to increase the safety, the efficiency and the happiness of mankind through the agency of lighting. This was the definite beginning of a new art and science and, owing to his intimate contact with various activities closely related to lighting such as gas and electrical engineering, the engineer assumed the responsibilities of lighting; hence the advent of the illuminating engineer.

In the early days of lighting as a distinct profession, the engineering aspects were given prominence. In fact, lighting is practised today largely from this standpoint notwithstanding that the efficiency and adaptability of modern illuminants have made possible the realization of the extension of lighting to meet very largely all the requirements of human activities and desires in respect to this agency. With this growing attention to lighting we find as in many other activities, that the deeper we delve the more extensive are the ramifications and comparatively smaller is the part of the apparent whole with which we are thoroughly familiar. For this reason, the physiologist and ophthalmologist have been attracted to the problems of lighting which involve the visual organs; the physicist specializes in many of the problems of production and utilization of light; the psychologist finds an unexplored field for his endeavors for finally the product of lighting is largely psychological; the artist finds an outlet for his ability in clothing scientific lighting principles with artistic exteriors in lighting fixtures, also in using lighting as a decorative medium by "painting" with light as obtained primarily from the lighting units. As we delve deeper into the problem of lighting we find many intimate relations between lighting and the various sciences and arts all of which must be appreciated by the lighting practitioner before he is worthy of the title of lighting expert.

The illuminating engineer should recognize that the esthetic sense, however dormant, is possessed by all human beings as is evidenced by the things about us. Perhaps we would not apply the term, artistic, to many of the scenes which greet us during our daily routine; however, as we critically view any of these scenes and eliminate in our imagination all that is not

purely utilitarian, how different they would appear! Imagine this done to everything on earth and a fair appreciation of the value of the artistic and beautiful is obtained. On the other hand, the artist should appreciate that in a broad sense in lighting, utility cannot be divorced from beauty. In fact, it is misleading to use these two terms as if they had nothing in common. Beauty in itself is certainly useful as viewed from the broad outlook upon life. Conversely, if a lighting fixture is intended to supply illumination for a utilitarian purpose and it fails to perform this function properly, it cannot be considered strictly beautiful regardless of its grace of line and of its proportions. The philosophy of the beautiful teaches us that beauty is the result of a harmonious ensemble of the various parts, hence in lighting fixtures beauty in a broad sense is dependent upon the harmony of science and art. In the design of fixtures we have a definite ground on which science and art should harmoniously intermingle.

But the consideration of the artistic aspect of lighting should not end at the fixtures. In fact, the greater field lies beyond them in the distribution of light upon the various surfaces such as ceiling, walls and floor, in the production of shadows appropriate to the setting and in the color which best fits the spirit or mood of the room or of the occasion. This is the most neglected aspect of lighting although it is one of the most extensive fields for development. Inasmuch as the prime object of the lighting specialist is to safeguard vision he seeks for rules which limit brightnesses and brightness-contrasts to safe values. Research is contributing much of value by direct attack on these problems. However, a rule which appears a safe one to follow, in the absence of any other simple and specific rule, is that if the lighting does not offend the finer esthetic sensibilities it is not likely to be seriously harmful in its physiological effects. Such a rule cannot be applied safely as a criterion of the best possible illumination but glaring lighting conditions have no place in an esthetic harmony of light, shade and color.

A specific aspect of lighting included in the preceding general discussion is the relation of lighting to architecture. The

appeal of architecture is chiefly through vision and the impression of proper proportions, of decorative value of details, and the harmony of the whole is gained through the distribution of light, shade, and color. Form and color are chief elements but lighting is of extreme importance in modelling form and in its effect upon the appearances of colors. Furthermore, the distribution of light upon the various surfaces influences the mood, spirit or impression of the interior as a whole. The architect visualizes all the elements of which lighting is an important one and aims to produce a harmonious blend of these in realizing that result which he has held in his imagination. His business is to consult specialists in all the sciences and arts which he must draw upon in producing the desired result and he is likely to lose confidence in the illuminating engineer if the latter's view is confined to the spacing of outlets and to computations which are confined to the supply of a certain intensity of illumination on the work-planes. The lighting specialist should be able to grasp the imaginative picture which the architect has kept before him and these two should work in harmony with the decorator and other specialists with the aim of obtaining from the lighting all of its potential value. Unfortunately this coöperation is not as general as it should be and attention is focussed upon outlets, fixtures and lamps without visualizing lighting effects and striving sufficiently to obtain them.

In the industries and in various other activities in which vision is severely taxed, the problems of lighting are not solved by providing a sufficient intensity of illumination on the work-planes. In each case the various specific activities should be studied in order to arrive at the best conditions for seeing. Sometimes objects on which the eyes are focussed are best seen as high-lights on a dark ground and in other cases as dark shades against a relatively brighter ground. The character of the shadows, which is determined by the position and angular extent of the light-source and by the amount of scattered light reflected from surroundings, is of importance in distinguishing objects. The color of the surroundings, the spectral character of the illuminant and the environment as a whole are factors

that should be considered and controlled by the lighting specialist in so far as he is able.

There are many scientific applications of color and colored light which are possibilities of the present and of the near future. Many of these will be touched upon in chapters which follow. These applications involve physical and chemical science in producing colored lights and effects; they involve physiological science in relating the spectral character to visual acuity, to the intensity of illumination and to other factors for best results; and they involve psychological science through their affective value. The possibilities of color in lighting are just beginning to be appreciated generally by lighting specialists but it is certain that these are very extensive.

As an element of safety, the lighting specialist finds much of value in lighting. Darkness and improper lighting are sources of danger and they are aides to criminals. Proper lighting not only conserves human resources but lessens the cost of maintenance of order in the community. To summarize the value and importance of proper lighting as an element of safety would be an insurmountable task but there are sufficient data to show that this is an aspect of lighting worthy of consideration. It should be the lighting expert's function to study and to rectify the many misuses of light such as insufficient lighting in dangerous places, the blinding effect of glaring light-sources amid crowded industrial plants and on the public highways, the proper illumination of danger signals, etc., all of which have extensive ramifications into various sciences. Another important view in this connection is the matter of lighting legislation in controlling the lighting of highways, public buildings, and parks, and the headlamps and rearlamps of vehicles.

Many other aspects of lighting might be discussed but the foregoing is perhaps sufficient to indicate the extensive importance of the subject. The attention given to lighting and the recognition of the lighting specialist are at present insignificant in comparison with the importance of lighting in human activities. This new science and art is young because it had small opportunity to develop until the advent of modern

illuminants. However, the past 10 years have witnessed tremendous growth in our knowledge and application of lighting. Much data remain to be unearthed but at least the lighting specialist is certain of his position and has begun the attack inspired by the conviction that lighting is a factor in industrial and commercial development and in prevention and safety; that it is not only an important economic factor but has great possibilities in adding to the pleasures of life. The entire subject cannot be covered in a single volume but it is hoped that in the following chapters new viewpoints and new possibilities will be presented. It is the intention to avoid treating aspects that are commonly discussed and regarding which data are readily obtainable from manufacturers. In so far as it appears practicable, discussions of specific installations will be sacrificed for discussions of principles for the reason that progress is made largely by those who are interested in *why* rather than in *how*. Present practice is bound to change and an interest confined entirely to this aspect results in imitation; principles are in general everlasting and interest in them leads to creative ability.

CHAPTER II

EXPRESSIVE POSSIBILITIES OF LIGHT

Nearly all problems of lighting may be considered as being divisible into two parts, namely, the purely utilitarian and the esthetic aspects, though as stated in the preceding chapter these are not completely separable and therefore no definite boundary exists between them. However, there is an advantage in lighting practise to separate these two aspects in so far as it is possible in the consideration and design of the installation.

In viewing lighting from the psychological and esthetic standpoints it is inspiring to note that no medium exists which possesses the expressive possibilities of light. The landscape artist who has striven to paint one of Nature's scenes with pigments may best appreciate this statement for with his pigments of extreme limitations in range of contrast and in purity of color, he strives in vain to record Nature's expression of light. Nature not only paints her landscapes with pigments but utilizes light as well. The latter might well be termed "primary" light to distinguish it from the reflected lights from the pigments in earth, foliage, etc. The painter, with brush dipped in terrestial pigments, is seriously handicapped for the reason that his media, under equal intensities of illumination, can only feebly represent that which is present in a landscape. His pigments under this condition represent a maximum range of contrast of about 30 to 1; that is, the whitest pigment is about 30 times brighter than the blackest pigment under equal intensities of illumination. However, the sun is millions of times brighter than some objects which it illuminates and the sky is many thousand times brighter than the deepest shadow. But the lighting specialist who paints with light can augment these contrasts as much as desired by controlling the brightness of the various parts, that is, by properly distributing the illumination.

In the matter of purity of colors the painter is not handicapped to such an extent in imitating the landscape because the colors of Nature are largely his pigments. But here again artificial lighting may excel the painter because it is possible to obtain approximately pure hues and even the pure hues of the spectrum if necessary. The latter is not a requirement of ordinary lighting but nevertheless it is a potential possibility which may find a field of usefulness eventually. The specialist who deals with light should at least be familiar with the potentiality of his medium.

The foregoing is an extreme illustration but there are many practical cases in which light is overwhelmingly superior to other media in its expressive possibilities. In other words, there is one aspect of lighting which can be described best as "painting with light." The decorator employs pigments in paints, wall-paper, and cloth fabrics to create a certain expression, apparently rarely employing lighting designedly in this connection. But the lighting specialist can do much to enhance the intended expression or toward defeating it. Suppose the decorative scheme in a given room to consist in general of grays of a "cool" or bluish tint, with the lighter shade on the ceiling and frieze and a slightly darker gray on the walls. Doubtless the grays have been chosen and applied under daylight illumination and the decorator does not always realize that the color and the distribution of light are playing parts in the effect obtained. Daylight usually enters rooms from side windows and rarely are the amounts of light admitted from the various sides equal in intensity. Furthermore, the illumination is usually more intense on the floor than on the ceiling. It is obvious that with common artificial lighting systems the distribution of light will be different and consequently the decorative scheme will be differently balanced. Incidentally the distribution of illumination from an ordinary direct-lighting system with pendant shades more generally simulates daylight distribution indoors than does the distribution of illumination from an indirect-lighting system. Under the artificial illuminants the cool grays usually change to warm grays which further emphasizes the expressive power of lighting. If the

grays are of a decided bluish tint their conversion to warm grays may perhaps be unattained without tinting the illuminant to the warmer color of the candle flame or even a deeper yellow. This is readily done by various means as will be discussed later. Such an application of tinted light changes very materially the impression of the room as a whole.

The expressive possibilities of lighting find extensive application in relation to architecture. Aside from the modelling of ornament, the light and shade effects of relatively large areas such as walls and ceiling, the contrasts in the brightnesses of alcoves with that of the main interior, and the shadows underneath ceiling beams are all expressions of light. These create certain moods appropriate or inappropriate depending upon the spirit of the whole interior. When an expanse of ceiling is apparently supported by beams, a dark shade on the under side of the beams completes the illusion of supporting ability. This illusion is best obtained by lighting because if it were created by the decorator doubtless under ordinary daylighting which is less easily controllable in distribution, the artifice would be evident because the lower sides of the beams would appear to be finished a darker shade.

A large interior of beautiful architectural proportions may be given a variety of moods by means of various appropriate distributions of light. When flooded with light from indirect units hung from the ceiling it has the airiness and extensiveness of outdoors. When lighted by means of units concealed in the upper cornice the ceiling will be bright and the walls are likely to be moderately dark by contrast. The feeling of being hemmed in by the walls and the illusion of an open roof above is not uncommon under such lighting. When lighted by means of low-hung chandeliers which direct much of the light downward, the ceiling and walls are likely to be moderately dark by contrast and if these are decorated with a medium shade the illusion is likely to be that of being hemmed in by the moderate darkness of the surroundings. Thus lighting is productive of illusions ranging from the mystery of crowding darkness to the extensiveness of outdoors. In such classes of architectural interiors the possibilities of lighting perhaps far exceed those

of decoration though as yet lighting has not taken its place even by the side of decoration as a recognized art.

To these possibilities and many more, the expressive possibilities of colored light, especially of the tints or extremely unsaturated colors, may be added. The expressiveness of tinted light is well displayed in the home. The warm colors of the old illuminants such as the candle and kerosene flames may be obtained readily from modern illuminants by the aid of colored media. The future will witness developments along this line which will make it easy to obtain the desired effects. There are many possibilities in applying colored illuminants of artistic tints to the decorative scheme, permanently or for various special functions. The tints which are applicable run the whole gamut of the spectrum in hue and include the pinks or rose tints. How such tinted illuminants fit the spirit of an occasion or the mood of a room may be appreciated only through experiment. Tints that are especially appropriate are warm yellow, rose, unsaturated green, and even light blues.

In such interiors as lounging rooms of clubs and hotels, living rooms, dining rooms, dens, and ball rooms, two or three different tints may be employed. A general soft illumination of a warm tint might be chosen but this may be effectually emphasized here and there by contrasting tints in portable lamps or bracket fixtures. Deeper tints of that used for general illumination may be employed sometimes for emphasis with good effect. However, there is a principle to be remembered in dealing with colored illuminants for their expressive value, namely, that colors live through contrast and die through lack of it. To take an extreme case, for example assume a room lighted with saturated red light. As the time of adaptation increases the purity of the red apparently disappears and the appearance of the whole room is that of a monochrome in an unsaturated orange. Even the red objects lose their purity of hue and such applications have little value except for psychological studies. Now inject into this monochrome a spot of light of any other color and the red bursts forth in all its purity of color. Contrast is essential to the life of colors.

A case less extreme and more endurable is to employ a deep

yellow illuminant. Many colors about the room disappear and the few remaining such as green, yellow, orange and red are crowded together. Place such an illuminant over the dining table and, for example, the butter is no longer appealing for it might be readily mistaken for lard. This experiment will dispel the mistaken opinion that yellow light brings out the yellow colors. In fact it drowns out the yellows for there are no striking contrasts to keep the colors alive. The same discussion applies to any illuminant that approaches monochromatism in spectral character.

Among the many installations of artificial daylight are found striking examples of the expressive powers of the color and of the distribution of light. In a large art museum where the artificial daylight units are concealed above the sub-skylight, the effect is so similar to daylight and the illusion so powerful that it is difficult to believe night has fallen. This example affords proof of the necessity of coördinating both distribution and spectral character of the illuminant for obtaining the effect. To the careful observer even this illusion is not perfect because of the symmetrical distribution of the artificial light, a condition rarely obtained with natural light except on overcast days. Those who study Nature's lighting are impressed with the directedness of the light except on densely overcast days. A knowledge of such details is essential in order to employ the expressive power of light to the limit of its possibilities.

To summarize the foregoing viewpoint in the most descriptive phrase it may be stated that the lighting-artist may "paint with light." The decorator and painter utilize light, shade, and color for their work but their tools are pigments, brushes, etc. Light and its accessories provide superior possibilities in obtaining beautiful effects. Quite the same esthetic principles are involved in this aspect of lighting, and artistic skill may utilize light in a vast variety of ways in the same interior thus producing various moods. The walls, ceiling and other areas are the canvases for light, shade, and color effects in lighting and the objects in the room provide real shadows. In a sense this aspect of lighting involves the combined principles of painting, decoration, sculpture, and architecture. Lighting fixtures and

outlets of the future will likely provide for these possibilities to a much greater extent than they do at present as the psychological and decorative aspects of lighting become more widely known and applicable and as the pleasures from variety in lighting become recognized.

CHAPTER III

VISUALIZATION

To state that visualizing a desired effect in lighting is the surest means of ultimately realizing the contemplated goal is merely to enunciate a corollary to the more general statement that imagination is the source of creative efforts. The ability to visualize is especially essential in approaching lighting problems in which the artistic aspect dominates, but it must be present in approaching any lighting problem. First, it is necessary to separate illumination and brightness which are respectively cause and effect. Illumination is independent of the surface at which it is measured but brightness depends upon the reflection-factor and character of the surface. Visualizing the effect of a lighting installation in terms of the illumination which it is expected to supply on various work-planes is not visualizing the actual lighting effects for the latter involve relative brightnesses and colors and their distributions.

Furthermore, lighting when done by considering only illumination is in general neither scientific nor artistic. The activities which are to be pursued at various points in the room should be considered and an attempt should be made to visualize the process of seeing in each case. Backgrounds against which the work is viewed are often of as much importance as the intensity of illumination. Lighting should have the aim of providing good seeing if this is essential and the visualizing ability is taxed in such a case as well as in producing artistic results where these are important. Lighting has not been developed to an exact science in its brief existence as a specialized activity so that it is quite legitimate to resort to experimental installations when possible; however, the necessity for such procedure decreases as the lighting specialist acquires knowledge of optical laws, lighting effects, optical characteristics of surfaces, effects of surroundings, etc., or in other words develops his ability to visualize results.

This view of lighting practice emphasizes the folly of attempting to plan lighting appropriate to a setting from blueprints alone. In order to do justice to the possibilities of lighting and to himself, the lighting specialist should be familiar with the architectural details, with the decorative ornaments, with the entire scheme of decoration as to colors and brightness distribution and with the intended spirit of the finished work.

Visualization is utilized to some extent in all work but this faculty must be highly developed before lighting practitioners evolve into lighting experts. This ability well developed is one of the characteristics which distinguish the lighting specialist or expert from the illuminating engineer, the meaning of the latter term being taken literally. The lighting expert, by becoming fully acquainted with the many aspects of light and its uses, by cultivating his esthetic sense, and by developing his power of imagination or ability to visualize, has fitted himself for his title because he is now capable of viewing the problems of lighting from that broad viewpoint which is bounded only by the limits of human activities.

In order to visualize in lighting it is necessary to know the simple optical laws; to be familiar with the optical characteristics of various kinds of reflecting and transmitting media; to be able to form a general idea of the brightnesses of the various surrounding areas under the different intensities of illumination which they will receive; to be familiar with the purpose of the lighting, the aim of the architect, and the plans of the decorator; and in general to be able to relate in the mind's eye the distributions of brightness and of color to the character of the activity and to the mood or expression which it is the aim to realize. Armed with this aggregate ability the lighting expert is prepared to begin the plans for a lighting installation with his eyes closed and his mind's eye open.

In order to further exemplify the importance of visualization in lighting and what is to be visualized let us inquire further into the process of seeing. The analysis of human consciousness reveals two kinds of visual sensations, namely, chromatic and achromatic sensations. No masterpiece of painted or sculptured art, no beautiful landscape, no office or

factory operation and no lighting effect, so far as the visual sense is concerned, consists of more than an arrangement or sequence of varied colors and brightnesses. In other words vision is accomplished through the ability to distinguish differences in light, shade, and color. If the image of any scene which is focussed upon the retina could be examined, it would appear as a miniature map of varied colors and brightnesses similar to that seen on the focussing screen of a camera. However, in the case of the eye only that part of the image which is near the optical axis is in true focus and the differences between the two records are further accentuated by the presence of physiological and psychological phenomena in the human visual process. In fact, the latter are the vast unknowns in lighting.

It is not generally enough recognized that the fundamentals of lighting are light, shade, and color effects for it is the variation of these factors which models and paints an object or an interior. No appreciable ability to visualize lighting effects can be developed without a painstaking study of light, shade, and color as related to the appearances of objects, to the physiological processes involved in vision and to the psychological phenomena associated with visual impressions. In other words, the expressiveness and revealing power of lighting are wholly dependent upon distributions of brightness and of color.

It should be easy to develop an ability to visualize lighting effects because demonstrations are everywhere awaiting the observer. The importance of color is omnipresent in the magical drapery in nearly all the scenes about us and the importance of high-lights and shadows and of the varied brightnesses of relative large areas may be studied everywhere in objects, landscapes, and interiors. Hence, it is helpful in developing the ability to visualize to divide lighting and its impressions into two parts, namely, that which depends upon the distribution of light and that which depends upon the quality of light.

The importance of visualization should be obvious after some consideration and the proof of this can be safely left to the reader. In fact, it is difficult to describe without the use

of actual demonstrations. Observation is the best means of investigating the importance of visualization but perhaps a few comments on specific cases may aid in helping those desiring proof to make their own observations. Let us take any ornamental interior where the architectural patterns are symmetrically distributed. If the whole is not to be uniformly lighted the problem of properly distributing the light is difficult because the various brightnesses often should conform to various individual areas, panels, or other patterns. Although in some cases a fairly uniform flood of light is appropriate, a decided lack of uniform brightness due to lighting is most generally conducive to artistic results. In such an interior the decorator almost invariably confines his different brightness boundaries to boundaries of patterns. But seldom, if ever, is the distribution of light confined to uniformity over a definite portion of the pattern bounded by architectural boundaries. To distribute light with exactitude in this manner is beyond practicable possibility because it would involve a fineness of control of light quite without the bounds of reason. However, this insurmountable difficulty does not justify the lighting specialist in making no attempt to obtain lighting accessories which will distribute the light in such a manner upon the various surfaces so that there is a more than accidental relation between lighting effects and decorative patterns. Here the ability to visualize is of value for it should result in a choice of suitable lighting units, a selection of the proper places for outlets, and a satisfactory mounting height of units. Sometimes designs of lighting units which are simple but uncommon may overcome the difficulty. A spotted and haphazard lighting effect may be avoided and lighting effects appropriate to the decorative patterns may be obtained. Only visualization will lead to such designs.

In planning a decorative scheme in the home, satisfactory results will be obtained only by maintaining in the mind's eye a picture of the desired result and by linking one by one the various elements of the whole. Lighting plays its part in this scheme and the choice of various types of direct lighting, of indirect and of so-called semi-indirect lighting must be made

early in the plans if a harmonious result is to be made certain. Here visualization is the definite means, aside from actual experiment, for determining the character of the installation and whether or not the artistic possibilities of asymmetrical lighting from portable units can be utilized.

Another case which may aid in suggesting studies of visualization is that of a beautiful architectural interior having high vaulted arches, columns, etc., such as a church. Certainly mood is a prominent factor in such a setting. A choice of an indirect system of lighting from suspended units or from sources concealed behind a cove, or of chandeliers, or of other systems must necessarily be the result of visualizing the appropriate lighting effect and of adapting the installation to it. A flood of light from concealed sources upon an expanse of high ceiling is just as appropriate in some churches as contrasty light and shade effects or dark ceilings are in others depending upon the character of the architecture and somewhat upon the denomination.

This brief discussion and these few examples should be sufficient to indicate the importance of visualization in lighting. This aspect of a lighting problem which should be one of the first steps taken in the consideration of a lighting plan is certainly much neglected or underestimated in value—a fact which may be readily proved by observing some of the methods of attacking and of solving lighting problems. It is not always neglected and in those cases where the value of visualization is utilized, the results are satisfactory testimonials of this value. Imagination and a knowledge of the scientific and artistic aspects of lighting is the combination which results in creative lighting.

CHAPTER IV

VARIETY—THE SPICE OF LIGHTING

Many observations and experiments have led the author to subscribe to the parodical title of this brief chapter. We demand patterns or texture in wall-paper, rugs, and upholstery, variation in light, shade, and color in the decorative scheme of an interior, ornamental architecture indoors and outdoors, frequent changes in the arrangement of furniture, and in many other ways express the human craving for change. Variety is one of the vital necessities for human endurance and even for existence. How strange it is that this innate demand for variety has not extended more definitely to lighting for, with comparatively simple expedients, no other source is so productive of variety. A few extra outlets for portable lamps, simple combinations of lighting principles in portable lamps and in suspended fixtures, two- and three-circuit fixtures each providing light of different distribution and possibly of different tint are possibilities for obtaining a distribution and color of light to suit the mood or the occasion. However, the provisions for obtaining variety in lighting seldom extend beyond a two-circuit unit providing only a possibility of varying the intensity of light, and a few connections for portable lamps, although simple combinations of accessories and of multiple circuits are sources of this most appealing feature of lighting.

Of all lighting systems, Nature's lighting is the least monotonous and a study of it leads to the conclusion that this is due largely to the perpetual change in distribution and color of light. When Nature's lighting is restricted in distribution and color as it is indoors by the artificial shackles constructed by man, its variety is suppressed and it often becomes monotonous and unsatisfactory. However, in the great outdoors, where Nature is unhampered, the lighting varies continually throughout a given day, as well as from day to day and from season to

season. It presents the extremes of variation in light-distribution on overcast and sunny days respectively and in the latter cases the shadows are continually shifting with the sun's altitude. The color aspect varies throughout the day from sunrise to sunset and no sunrise, sunset, or landscape ever presents identical appearances at different times.

If a certain landscape be studied throughout the day usually it will be found to be most interesting and enticing during early morning and late afternoon on a clear day because of the presence of variety due to long shadows. Nature's scenes lose much of their appeal on overcast days when there is less variety of light, shade, and color. Incidentally, Nature provides excellent opportunities for studying this aspect of lighting and others because a vast array of different distributions of light are present on every hand. The variations in the brightness and color of a landscape and in the distribution of light owing to intercepting foliage provide many studies in lighting effects.

Variety in lighting not only includes the different distributions of light and color attainable by the lighting equipment primarily but also the variety in the distribution of light, shade and color in a given case. In many interiors, symmetry is a keynote and in such cases, symmetrical lighting effects harmonize with the whole. But in most interiors, such as living rooms, restaurants, and lounging rooms, symmetrical lighting effects are unnecessary and are often monotonous, inartistic and even obtrusive. For example, let us take the case of a living room which is occupied for long periods nightly. To one possessing a fine sensibility it is extremely monotonous to be greeted with the same symmetrical distribution of light from the ordinary central fixture. If two circuits are provided for this fixture a slight relief is available by variety in intensity especially if unbalanced by the light from a library lamp asymmetrically located. If fixtures are provided with accessories which make it possible to obtain two widely different distributions of light, it becomes possible to provide a lighting more in sympathy with the mood and thus to relieve the monotony to some extent. Table lamps and brackets lend variety which pleases the finer sensibilities and aid much in providing means for adapting the

lighting of the room to the mood or to the occasion. In fact, it will not be surprising to find that central lighting fixtures in such rooms will be less used as the possibilities of variety in light, shade, and color in a given lighting effect and of a variety of different lighting effects become more appreciated.

However, symmetry in distribution of light is appropriate in such a case as the dining room where necessity demands it and the setting would be incomplete without it. However, even in the dining room there is much pleasure to be obtained from a central fixture which provides different distributions of light and the possibility of introducing tinted light when desired.

On viewing an art exhibition with a great artist where daylight quality of light had been simulated by artificial lighting units placed above a slightly diffusing skylight, the artist remarked that the quality of light was excellent and that the light was evenly distributed, but that daylighting in a broad sense had not been entirely imitated. Something was missing which upon further discussion proved to be a degree of directedness or lack of symmetry required by the artist's fine sensibility which had often communed with Nature. That this artist was correct in his deduction, which was arrived at not through an acquaintance with the bare scientific facts but through the impressions which lighting had made upon him, is readily concluded upon studying Nature's lighting. It is also evident that training in esthetics yields much of interest in lighting even though the individual facts are not laid bare by careful analysis. Associations of this character would alter the attitude of the illuminating engineer who scoffs at the esthetic and other psychological possibilities in lighting.

The magnitude of Nature is great enough to play an important rôle in the making of a human mood; that is, our moods often readily fit themselves into that of the natural environment outdoors. We have all responded to the cheerfulness of a sunny morning and have been depressed by the overcast day. Occasionally if great sorrow or great joy is sufficiently intense even Nature's smile or frown cannot alter it but in general Nature's mood is the dominant one. However, the human mood usually desires to dominate the artificial setting perhaps

because of the knowledge that the latter is artificial and therefore may be altered. For this reason means should be provided for adjusting the lighting in harmony with the mental state or with the spirit of the occasion. This is readily possible only when such means are provided, though rarely is this factor considered sufficiently.

Lighting units are appearing on the market which are designed to satisfy this innate desire for variety to a limited degree at least. The so-called direct-indirect units make it possible to alter the distribution from a concentration of light in a small area leaving the remainder of the room in twilight, to a flood of light over the entire room when the mood or occasion demands it. Portable units and brackets, asymmetrically located, carry this idea further so that it is readily possible to obtain a harmonious distribution of light, shade, and color. There are a few fixtures in which direct units are combined with a semi-indirect unit. When the direct and semi-indirect units are placed on separate circuits some relief from the usual monotony is possible. However, such units are not in general use and the fault lies perhaps in the lack of appreciation of the pleasures from variety in lighting on the part of the illuminating engineer, the fixture manufacturer, the contractor, and the consumer.

Although the means for obtaining variety in distribution of light in present lighting installations are meager, those for obtaining variety in color are even rarer. There is a demand, continually growing more definite and insistent, for tinted lamps for the purpose of obtaining variety in color in lighting. The purer colors may have fields in this respect but artistic lighting in most interiors will be confined to delicate and barely perceptible tints which are more "felt" than seen. At present silk shades are popular and it appears that much of this popularity is due to a desire for tinted light. The light transmitted and reflected by such fabrics is tinted, and beautiful effects may be obtained by applying textile shades to light-sources. There is some tinted glassware available and units have been devised for quickly altering the color effect by changing the silk coverings of semi-indirect bowls. Colored gelatines and

colored glasses are available but not in such a practicable form as to be readily adaptible to general interior lighting fixtures.

The greatest possibilities in introducing tinted light into interiors lie in employing colored lamps in multicircuit fixtures. By mixing these tinted lights a variety of tints may be obtained. Although approaching the theatrical, there are delightful possibilities in using colored lamps such as primary red, green, and blue, controlled by rheostats which may be concealed in the wall. By varying these components of colored light any desired tint may be obtained. Such an arrangement has been used by concealing the lamps above a panel of diffusing glass set in the ceiling. This provides great possibilities in fitting both the intensity and color of the light to the mood or occasion.

Many other possibilities present themselves to those who appreciate this aspect of lighting. An artificial window covered with lattice and foliage may provide either artificial moonlight or sunlight as desired. For example, the former provides delightfully restful lighting for lounging or for musical renditions while the latter in congested residential districts would be welcomed very often. Other devices such as vases and imitation flower-boxes on pedestals, on the mantel or on the walls provide places for concealing light-sources which at the proper time add pleasure to an otherwise monotonous lighting. One would hesitate to attempt to describe the possibilities in lighting which would be exemplified by a lighting specialist who was given *carte blanche* while the plans were being made for a residence in which the psychological possibilities of lighting could be fully utilized. Some of the foregoing suggestions may appear extreme and out of place in a discussion of lighting, however, they have been tried with pleasing results. In general, lighting will never attain a high level as an art until the attention is more definitely directed toward realizing many of its untried possibilities.

To summarize, monotony in lighting can be avoided only by providing means for varying the distribution and quality of light. Fixtures of today are generally too simple in wiring and design to give artificial lighting an opportunity to compete with

Nature's lighting outdoors in gaining the favor of the finer human sensibilities. The advent of a few lighting units designed to furnish a degree of variety of light, shade, and color is perhaps an indication of economic and esthetic demands, but progress in this direction has barely begun. It is believed, when the full import of variety in lighting has become appreciated by lighting specialists, fixture designers, contractors, and consumers, the procedure of lighting many classes of interiors will be altered considerably and that lighting fixtures and tinted lamps adaptable for providing this variety will be more generally available. This aspect will crop out occasionally in other chapters.

In closing this chapter, which treats an aspect of lighting possessing vast potentiality, we might summarize in a few words appropriate to lighting as well as to life. Variety leads us happily through a colorful sojourn; monotony condemns us to a colorless existence. Monotony is a monochrome and, true to the laws of color, it loses its color through continued adaptation. Variety is a mobile painting in light, shade, and color done by a master colorist, and it provides perpetual interest as it is altered to suit our mood or fancy. In thinking of variety in lighting the metaphorical phrase, "painting with light" seems most appropriate.

CHAPTER V

DISTRIBUTION OF LIGHT

The preliminary steps in any analysis aim to subdivide the problem into a few broad aspects and later to assume various viewpoints in considering these. In lighting it is often advantageous to divide problems of planning or of analyzing lighting effects into two broad though interwoven parts, namely, distribution and quality of light. To describe all the ramifications of either of these factors would be a task whose record would greatly overflow the confines of a single volume, but chief features of these two interwoven aspects form the major part of the discussions recorded in this book. One advantage of this division is that the effects of color are separated from those of distribution of light. In other words, the latter aspect would constitute the entire consideration of lighting by a color-blind person. It involves much more than the distribution of light as emitted by light-sources and controlled by reflectors, shades and other accessories, for it includes the distribution of illumination and brightness upon the various areas such as walls and ceiling, the formation of shadows, and many other factors.

For the consideration of the distribution of light from light-sources and their equipment, engineers and scientists have supplied excellent data and this aspect of lighting has been highly developed. Light-sources have been modified in character in many ways which adapt them to the many requirements of lighting and a great many accessories have been designed for the purpose of obtaining various distributions of light for the rapidly growing demands. As a consequence, lighting units are available for highly diffusing the light, for concentrating the flux into a powerful beam or for many of the possibilities between these two extremes.

In the consideration of the distribution of illumination and brightness in the visual field both the artistic and purely utilitarian factors intermingle. This aspect of distribution of light is least considered and developed yet it is the most important because it involves the effect. The cause is only of incidental interest in lighting for the primary purpose is to obtain a lighting result and therefore much study and analysis should be applied to effects. The interest of the lighting specialist should not cease on determining the positions of the outlets and on choosing the lighting equipment which will provide a certain intensity of illumination, but these should be selected with the aim to obtain a certain previsualized effect. The desired result, whether chiefly artistic or predominantly utilitarian, involves much more than illumination intensity on a given plane. This point has been mentioned in previous chapters and will be discussed in others for it is one of the most vital though one of the most ignored factors in lighting practice.

Before discussing the distribution of light as pertaining to lighting effects, a few points will be brought out regarding lighting units which are simple though often overlooked. Simple expedients are often the finishing touches which are needed in order to make the lighting result completely satisfactory. From the standpoint of lighting effect the direction of the dominant light is important because of the general direction of the shadows which are produced. Shadows are usually essential for good seeing and for artistic effect but the character of the shadows varies considerably depending upon three factors. The direction of the shadows depends upon the position of the dominant light-source. The character of the edges of the shadows, that is, of the modulation in brightness from the deepest shade to the brightness of the surroundings or background, depends upon the solid-angle subtended by the light-source at the shadow-producing edge. The appearance of the shadow-edges is extremely important both from the purely utilitarian and purely artistic viewpoints. This may be readily proved by comparing the shadows due to a clear concentrated filament lamp with those obtained after a small diffusing globe has been placed over the light-source. The dif-

ference is very noticeable even with clear and frosted or opal lamps in an ordinary table lamp. Furthermore, the difference is not only noticeable but the relative desirabilities of the two light-sources are usually easy to ascertain. Consider the upper edge of an opaque object *O*, Fig. 1. The appearance of the shadow-edge on the surface *S* will be the same for the light-source of the magnitude of *AA* as for *BB*. It will be noted that although *BB* is larger than *AA* it is more distant and the solid-angle is equal in the two cases.

Another point worthy of note in this connection is the effect of the image of the light-source reflected from glossy surfaces.

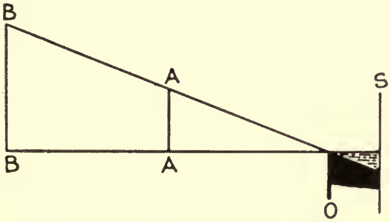


FIG. 1.—Shadow cast by an edge of an opaque object.

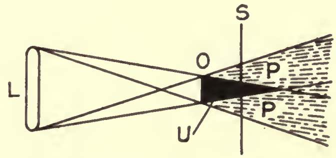


FIG. 2.—Shadow cast by a small object. U, umbra; P, penumbra.

Usually a source of low brightness is less annoying although this is not always true when the light-source subtends a large solid-angle because it is difficult to avoid seeing a portion of the reflected image. However, this is largely dependent on the character of the surface and as a consequence it is well to avoid the use of glossy surfaces. There are special operations, such as the surfacing of metal, which depend upon specular reflection for close inspection of the results; in these cases a light-source subtending a relatively small solid-angle is usually desirable.

Shadows are also affected by the amount of scattered light received from the surroundings. If there were no scattered light the shadows would be black except for the penumbra as shown in Fig. 2 where *L* is the light-source; *O*, the opaque object; *P*, the penumbra; *S*, the receiving surface; and *U*, the umbra. The umbra receives no light except from the surroundings. The illumination of the umbra varies with many conditions but measurements indicate that this is of the order of

magnitude of 5 to 15 per cent. of the adjacent illumination under ordinary lighting conditions. Harshness or severity in effect is obtained by means of dark, sharp shadows. It will be noted that the appearance of the shadow will be altered on moving *S* farther from the object. In the case of small objects and ordinary light-sources these shadows become quite inconspicuous if cast on surfaces which are not close to the objects. A few studies of shadow-formation by means of simple observation are helpful in lighting practice.

Some of these points will be discussed in connection with lighting units to further emphasize the importance of these details. The light at a given point in a room may be extremely diffused when received from the ceiling which is illuminated by means of a so-called indirect unit. Although the resultant diffusion may not be materially different, the appearance of the ceiling will depend upon the character of the primary light-source and upon other factors. The indirect unit is in principle, a shade and a reflector combined and inverted. If a concentrated light-source is used the shadows of the edge of the bowl or of the supports will appear sharply outlined on the ceiling. By frosting the lamp or by otherwise enclosing it in a diffusing medium, the effective light-source is made to subtend a large solid-angle at the edge of the bowl or at the supports, owing to its proximity to these, and the shadows are no longer harsh. These objectionable shadows may not be eliminated entirely by this method if only one light-source per lighting unit be used but those remaining will be indefinite and often the effect is more artistic than if absent entirely. Artistically there are few places for harsh shadows in lighting.

The foregoing also applies to semi-indirect bowls and shades and many harsh effects could be eliminated by such simple expedients. Very often a harsh spot on the wall adjacent to a bracket fixture may be softened by replacing the clear lamp with a frosted lamp, by placing a sheet of sand-blasted glass or other diffusing medium over the aperture of the shade, by scalloping or corrugating the edge of the shade and by other obvious methods. The shadow-effect of a bare light-source is rendered less harsh even by an opaque aluminized or enamelled

reflector because the light-source now consists in reality of two light-sources, namely, the bare lamp and the reflecting surface. Often semi-indirect bowls appear spotted and ugly because of the improper mounting of the light-sources within them, although in order to present an artistic appearance, the bowls need not present a perfectly uniform appearance. Some of the most beautiful appearances of such luminous bowls are due to non-uniform brightness-distribution in which the light and shade is delicately blended. The artistic possibilities of variety extend to such bowls as well as to lighting effects as a whole.

Various reflectors giving asymmetrical distributions of light are available for use on brackets and behind cornices and these make possible the production of some excellent effects in lighting. They perform the double function of eliminating the conspicuous adjacent bright spot, which is one of the objectionable features of the ordinary unit, and of projecting the light to other parts of the ceiling and walls where it may be desired. Such units have greatly extended the possibilities of lighting by means of fixtures supported on the walls. They may be placed on brackets, concealed in imitation flower-boxes or behind decorative ornaments, or hidden in recesses designed by the architect. Such units of asymmetrical distribution have wide applications in many places such as corridors, rotundas, large rooms, and even in the home.

Artificial lighting systems are commonly divided into three broad classes, namely, direct, semi-indirect, and indirect systems, although this classification has no other justification than that of convenience because there are no definite boundaries between the classes and much less distinction between them on the basis of the lighting effects which are obtained. A light-source equipped with a pendant opaque reflector may be called a direct-lighting unit. If this unit be inverted it becomes an indirect-lighting unit because the light reaches the working area indirectly by reflection from the ceiling, walls, etc. Between these two extremes we have an infinite variety of lighting units and lighting effects.

If the pendant opaque reflector be replaced by an opal or prismatic glass shade, the unit is ordinarily considered a direct-

lighting unit although the lighting effect has been altered very considerably. If this unit be inverted, we have what may be termed a semi-indirect lighting unit. With the wide variation in the densities of glassware and in the design of lighting units employing diffusely transmitting media, there is a great variety in lighting effects which may be included in the classification of so-called semi-indirect lighting. Considering the light

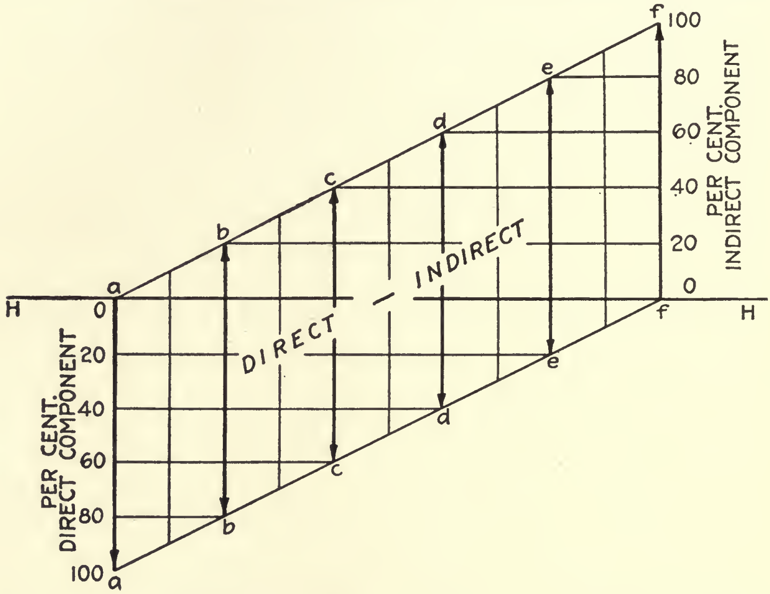


FIG. 3.—Diagrammatic illustration of the distribution characteristics of lighting units.

density glass bowls the lighting effect may be comparable with that obtained from the pendant diffusing glass ball though the latter is never classed as a semi-indirect unit.

The simple diagram shown in Fig. 3 illustrates all possible combinations of direct and indirect (downward and upward) components of light flux obtained from lighting units. For the sake of being definite, the downward component might be considered that portion of the total output of light-flux which is emitted into the lower hemisphere, and the upward component that portion emitted into the upper hemisphere. The horizontal plane *HH* may be considered to pass through the

center in the lighting unit which must be considered to be without dimension for the sake of diagrammatic illustration. Purely direct lighting is represented at *a* and indirect lighting at *f*. Between these two extremes is a vast variety of direct-indirect lighting. It appears that scientific lighting terminology would be simplified and rendered more definite if the term "semi-indirect" should be replaced by the term direct-indirect. A given unit could then be specified in such a manner as direct-indirect, 30–70, which would signify a 30 per cent. downward component and a 70 per cent. upward component and thus eliminate the confusion and indefiniteness of the term "semi-indirect."

Satisfactory semi-indirect units are usually found to have characteristics in the region between *e* and *f*, Fig. 3, and the so-called luminous-bowl units possess characteristics approaching close to *f*. If the lighting units are exposed to the normal field of view it has been fairly well established that their characteristics as to upward and downward components ordinarily should lie between *e* and *f*.

A more definite requirement in practice is a quantitative limit of brightness because a large diffusing glass globe or bowl of light-density glass would be satisfactory if the luminous output of the light-source were sufficiently small. If a light-source of high luminous output were used in such units the brightness of the diffusing glass might exceed the satisfactory limit. The brightness of such units as established by what is considered good practice at present varies from 0.25 to 1.0 candle per square inch or approximately from 0.125 to 0.5 lambert (125 to 500 millilamberts). For the more exacting work where the position of the observer is definitely fixed the lower values are preferable. There are many factors such as brightness-contrast and the position of the units which determine the limiting brightness so that it is impossible to be very definite without discussing these factors at great length. Specifications of brightness apply to the unit as installed and equipped with light-sources whereas the direct-indirect classification has the advantage of definiteness regarding the distribution of light obtainable from the unit.

Such a classification or specification of lighting units in terms of direct and indirect components appears to satisfy certain practical requirements of definite description of the characteristics of individual units but there is still a lack of definiteness in the description of lighting installations in general, unless such a classification be applied to the distribution of light as a whole. Cove-lighting in which the light-sources are concealed behind a projecting moulding or cornice would be correctly classified as indirect lighting and there appears to be no reason why the direct-indirect terminology could not be applied to the distribution of light by the lighting system as a whole as determined at any point of interest. However, no such classification can be applied to the lighting effects because these are measured in terms of brightness-distribution which depends upon reflection-factors and therefore upon many elements such as decoration.

The foregoing discussion has dealt with the common artificial lighting systems from the standpoint of distribution of light; however, the distribution of daylight in interiors is important not only by itself but in connection with artificial lighting. There is much of interest in the study of daylight distribution because it presents more widely different effects than are commonly encountered in artificial lighting. Oddly enough, relatively little study has been applied to daylight distribution compared with the vast amount of measurements which have been applied to artificial lighting. A need in lighting practice is a more general analytical study of the distributions of illumination and of brightness on various planes and at various points instead of confining the studies to the so-called horizontal or other work-plane. These measurements are gradually being extended in scope and it is certain that they are resulting in material progress in the proper use of light. Although quantitative measurements are desirable, much is to be gained by qualitative analyses of the varied lighting conditions about us.

In general, daylight indoors varies widely in distribution from that obtained from any ordinary system of artificial lighting except in the relatively rare cases where overhead diffusing skylights are used to admit daylight. Daylight usually enters interiors from vertical openings at the sides of the

room and inasmuch as most of the light is directed through these openings from the sky or sun overhead, the illumination is usually of the greatest intensity on the floor. In order to simulate the distribution of brightness outdoors to which the eye has been adapted for ages, there doubtless arose the habit of using floor-coverings of a dark shade and of finishing the ceiling and upper parts of the walls in lighter shades. Although the illumination of the ceiling under these daylighting conditions is usually of a much lower intensity than that of the floor, the light which reaches it by reflection from the floor, walls, and objects outdoors, does not suffer much absorption because of the usual high reflection-factors of ceilings. The effect is therefore one of high brightness for the ceiling and upper parts of the room and of lower brightness for the floor, notwithstanding the greater intensity of illumination on the floor. The illumination distribution is sometimes reversed when there is snow on the ground and on other objects. In fact, it is interesting to note the tremendous change in the natural-lighting effects in a room from season to season and sometimes from hour to hour. The foregoing is an excellent illustration of the difference between illumination and brightness; that is, between cause and effect.

From the viewpoint of distribution of light in an interior the direct-lighting system usually more nearly simulates daylight indoors in most cases than does indirect lighting. Brightness measurements and others are very convincing in this respect. But there is generally an outstanding difference in the distribution of artificial light and of daylight indoors, namely, the dominant direction of light. This results in a different direction of shadows, which aside from the color-difference is perhaps by far the greatest source of annoyance. Many industrial operations and many other interior settings are adapted to daylighting and the sudden change or conflict in the direction of shadows when artificial light is called upon to reinforce waning daylight causes such annoyance that this period of the day is often unsatisfactory. There appears to be an additional annoyance where the difference in color of the two illuminants is conspicuous as it usually is. In such cases it is often more

advisable to make the change completely from natural to artificial light for after a few moments the eyes become readjusted and the operator may shift himself or his work to a more satisfactory position.

It is not impossible or even impracticable in some cases to place the artificial lighting units so that the dominant direction of light is approximately the same as that of daylight and when the illuminant approximates daylight in color the day wanes and night falls without being noticed by the busy person. The greatest obstacle against such an asymmetrical installation of lighting units in cases where this is practicable, is the prejudice and habit of the lighting practitioners. This plan has been used in some cases for bench work, office work, and in other places but these represent exceptional practise. It is certain that this procedure will be more general where it is practicable as the science of lighting becomes better defined and more exactly practised. In many cases where the function of artificial lighting is merely to aid daylight during its waning hour this appears to be wholly practicable. Such cases are to be found in school rooms, offices, shops, etc. However, there are many cases where artificial lighting is used for many hours of the day and in these it appears best to take advantage of the superior possibilities of artificial lighting and to use daylight merely secondarily.

In simulating the distribution of daylight indoors it is possible to illuminate walls by means of shaded units and to obtain the proper distribution and diffusion of light indirectly by reflection. This has even been carried farther by placing in the window openings, screens of high reflection-factor and illuminating them by means of shaded units. Such distributions of light have not been displeasing and have been useful in overcoming the difficulties of the usual conflicting shadows. In large reading rooms, for example, where the proper direction of light is from the left of a person as he sits reading or writing, the furniture and artificial lighting units might well be placed in such a position that the person would be equally satisfied with daylight or natural light. There are many practicable possibilities of such a coördination of distribution of natural and

artificial light among the vast variety of problems which confront the lighting specialist and the realization of these possibilities will be found along the highway of future progress in lighting.

In this chapter an attempt has been made to point out the general importance of distribution of light in extracting from among the many possibilities that which best solves the problem at hand. The subject is as extensive as lighting itself because the question of distribution of light is involved in every problem regardless of magnitude. It is discussed in nearly every chapter of this book but a few specific points have been brought forth here in order to emphasize the possibilities. The distribution of light as obtained from the ordinary systems of lighting have their place in lighting and the problem usually is to select that which produces the desired effect. However, progress will be marked by combinations of these distributions and by special ones devised for solving unusual problems. In lighting it is the effect that is sought and in obtaining this the lighting unit is only a necessary link for through it and the other attendant factors the desired result is obtained by a satisfactory distribution of light and color.

CHAPTER VI

LIGHTING FIXTURES

The chief problem in the design of lighting fixtures is, in general, to combine beauty with utilitarian or practical value. The evolution of lighting fixtures may be definitely traced along two lines, namely, the artistic and the scientific or practical and in a relatively small percentage of available fixtures have these two lines merged harmoniously into completely satisfactory results. Inasmuch as the importance of proper-lighting principles has become widely appreciated only within a comparatively recent period, it is not surprising to find that the artistic viewpoint was the dominant factor in early fixture-design. In fact, the problems of fixture-design were early placed in the hands of the artist who even today is largely the dominant factor.

Although there are vast possibilities in utilizing light as a decorative medium through lighting effects beyond the fixture, it is relatively rarely used with this as a primary aim; therefore it is logical to conclude that the primary purpose of lighting fixtures is to provide light for utilitarian or practical purposes. We thus arrive at a paradoxical condition in which the scientific application of light is found to be chiefly in the hands of the artist except in purely utilitarian lighting such as is found in the industries. Naturally the artist's thought and energy is directed toward harmony of line, proportions, and other decorative features and often through lack of knowledge or appreciation of the value of scientific lighting principles, an artistic fixture is produced which fails to perform its chief function in the best manner.

But may a fixture be beautiful if it fails in its chief function of practical utility? The vast literature on the philosophy of the beautiful renders a negative answer for beauty is "visible perfection, an imperfect image of the supreme perfec-

tion"—a result of harmony or the accord of all the elements such as lines, masses, colors and finally artistic and practical functions. Notwithstanding the theoretical and idealistic conclusions arrived at by the philosophers in the realms of beauty and value, it is well to bear in mind both the utility of beauty and the beauty of utility if for no other reason than for the inspiration to strive to unite the practical and the artistic aspects in lighting fixtures.

On surveying the past in lighting it is easy to imagine the designing artist so absorbed with such elements as form, grace, rhythm, color and expression that he neglected the principal object of the fixture—its usefulness as a *lighting* accessory. Similarly it is easy to imagine the lighting engineer so engrossed with the scientific aspects of lighting that he neglected to cultivate an appreciation of the artistic aspect. It is not a simple task for an individual to cultivate both viewpoints to a high degree but it is possible. Dual experts of this character are rare but the harmonizing of science and art in lighting fixtures can be accomplished by a closer coöperation between the designing artist and the designing engineer. The past bears witness in many cases to the absence of such combined efforts. Fixture catalogues of today, although showing a mingling of these two viewpoints, present a variety of examples which pictorially represent the progress of science and art toward each other. Fixture design has evolved largely from the purely artistic viewpoint and in this field lies the opportunity for perfecting the harmony of usefulness and beauty in lighting.

It is not always a simple task to combine the artistic with the practical; that is to design the skeleton of a scientific *lighting* fixture and then to provide it with an artistic exterior. It is satisfying to note that such attempts are more frequent now than in the past and it is easy to discern by their output those fixture manufacturers who are working toward this ideal. They represent the successful and progressive manufacturers of today. An idea of the amount of progress still to be made toward the harmony of science and art in lighting fixtures may be gained by visiting fixture display-rooms with the chief thought of the foregoing paragraphs dominating the mind. If a sacri-

fice must be made in harmonizing the practical and the artistic, let it be, in most cases, a sacrifice of efficiency in its narrow sense. The accomplishment of the practical and artistic aims simultaneously, even at the sacrifice of some light, results in an efficient unit in the broadest sense. One handicap in the design of lighting fixtures has gradually been lowered as the efficiency of light-production has increased and today we may well afford luxuries in lighting if a few years ago we could have afforded the pure necessities for the cost of light has greatly diminished. It does not appear that the general progress in the design of lighting fixtures has kept pace with the decrease in the cost of light if fixtures of the past were justifiable.

The lighting fixture is a means to an end; its place is always between the meter and the eye. For this reason it is, doubtless, the most important factor in the art of illumination and may be considered from many viewpoints, those of the manufacturer, of the salesman, and of the lighting specialist, being of special interest here. These persons should know the principles of the art of lighting but unfortunately some manufacturers and many salesmen know relatively little of either the scientific or artistic aspects of illumination and the lighting specialist seldom qualifies as a lighting artist. Fixtures are too often made and sold as a product quite independent of lighting. Unfortunately the consumer is usually quite indifferent or ignorant of the finer points in lighting so that faulty fixtures and lighting effects pass without protest and scanty stimulation is given to progress in these directions except by lighting practitioners. Owing to these various conditions it may be stated with confidence that one of the greatest deterrents to progress in proper lighting is the faulty lighting fixture which is made in great numbers and sold to an unsuspecting public.

The art of illumination involves physical optics, physiological visual phenomena, and psychological effects of light, shade, and color as well as engineering principles. This brief sentence covers a field which has numberless by-ways from the physics of light-production to the esthetics of lighting effects. The manufacturer should sort out from the vast amount of available data the specific knowledge which should be utilized in the

design of lighting fixtures for he cannot conceive and execute proper lighting fixtures with certainty without such knowledge. The array of such products which greets one in catalogues and in display-rooms is evidence of the truth of the foregoing statement and the small percentage of thoroughly commendable fixtures is evidence that the statement should be repeated far and wide. But progress is being made by a number of manufacturers and it is easy for the lighting specialist to recognize the product of those who are combining knowledge of the scientific facts of proper lighting with esthetic taste.

More discouraging than other aspects of the fixture situation is the salesman's lack of training in the principles of scientific and artistic illumination. Relatively rarely is the consumer guided in his choice of lighting equipment by a salesman whose interest lies in selling proper lighting for he apparently does not realize that the customer has really come to purchase lighting and not merely to buy lighting fixtures. This is a condition in fixture stores which is not universal but from many explorations into such stores the author is emboldened by his experiences to state that the condition is quite general. Why would it not be a matter of good business in selling fixtures to give proper lighting as good measure in the transaction? Some progressive fixture dealers are doing this with excellent results and service in lighting should become a slogan of the fixture dealer. Finally, we cannot avoid the conclusion that the average consumer is in an unfortunate position hemmed in by indifference to and ignorance of proper-lighting principles. He is not a lighting expert nor could he afford to ask the advice of one even if he knew that it would be to his advantage to do so. He must depend upon his own judgment, the dealer's reputation, or the salesman's recommendations. If neither he nor the salesman is qualified to choose a proper lighting fixture it is left to chance and owing to the relatively low percentage of eminently satisfactory fixtures in an average display, his chance of obtaining a suitable fixture is small. He will be easily influenced by the salesman so that progress in good lighting must depend largely upon the salesman's ability as a lighting specialist. Experience indicates that many salesmen

are more concerned with the popularity of a certain design than with meeting the consumer's individual requirements, with the result that there is a vast number of fixtures in use today which should never have been sold or even made.

Viewed from the broad aspect of the art of illumination the problem of getting proper lighting fixtures made, sold and properly installed is an overwhelming one at the present time yet it must be solved before general progress in scientific and artistic lighting will be made. There are three points of attack which in the order of their choice, are perhaps manufacturing, selling, installing. More knowledge of lighting is required in the conduct of each of these activities and if they are well done the public will eventually become familiar with the usefulness and pleasure inherent in good lighting.

It is not a primary aim in this chapter to discuss the many details of good and bad lighting fixtures for the reason that such a discussion would be very extensive and would lead far into the incompletely explored regions such as the conservation of vision, visual efficiency, and esthetic principles. Many aspects of these fields have been widely discussed in lighting literature so that the progressive manufacturer, salesman, architect, or illuminating engineer may readily assimilate from these the knowledge which he requires. An aim of all concerned with lighting fixtures should be to safeguard vision and to add to the efficiency and pleasure of mankind by means of proper lighting.

From the practical standpoint the fixture should shield the primary light-source from ordinary view and excessive brightnesses of transmitting and reflecting media should be avoided. Contrast plays an important rôle in visual comfort and the maximum permissible brightness depends upon the brightness of the surroundings. A bare incandescent lamp may be viewed against a bright sky without serious discomfort but when viewed against dark surroundings or even against the ordinary background in an interior it will be glaring. This is an example of the importance of contrast in lighting. In the so-called semi-indirect systems, more definitely described as direct-indirect systems, the glassware ordinarily used is often not dense enough. Of course the satisfactoriness of a given diffusing glass bowl

depends upon the positions and luminous output of the light-sources inside the bowl but in general the light-density diffusing glasses, as commonly used, are too bright for comfort unless hung quite high. The same is true of diffusing glass shades. The permissible maximum brightnesses of lighting equipment are not definitely established and depend upon so many factors such as the brightness of backgrounds and the hanging-height that it appears inadvisable to attempt to present quantitative data, although a safe maximum limit for ordinary conditions will perhaps be found to lie between 0.1 and 0.5 lamberts. For the sake of comparison the average sky-brightness may be considered to be about 1 lambert. General experience and observation must be depended upon at present for conclusions regarding these brightness factors but the tendency should be generally toward lower maximum brightnesses and contrasts than are commonly encountered.

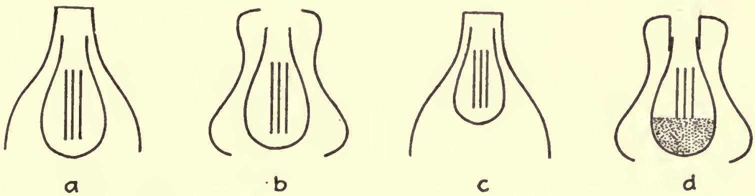


FIG. 4.—Illustrating simple though important details in lighting.

Throughout lighting practice the correction of apparently minor details, by means of simple alterations, works wonders and this applies with equal force to lighting fixtures. For example, a shower with small pendant glass shades may be unsatisfactory if hung too high because the bare lamps may be visible. If the glassware is sufficiently dense no other alteration may be necessary than merely lengthening the supporting chains or rods. It may be that the shades are not deep enough or that the lamp projects too far downward so that the light-source is visible. By using a shorter lamp, by bowl-frosting the lamp if it is of the electric incandescent type, or by providing shades of a different shape with a smaller aperture, the fixture may be made satisfactory. Some of these points are illustrated in a simple manner in Fig. 4 where under certain conditions *a* may be unsatisfactory and *b* satisfactory owing to a

slight alteration in the shape of the shade. By using smaller lamps as in *c* or a deeper shade, condition *a* may be improved. By bowl-frosting the lamp as in *d* an improvement over *b* may be gained in some cases. Such simple details in lighting are often very important.

The artistic scheme of certain types of fixtures appears to demand the use of unshaded frosted lamps, but unless these are hung high in the ordinary interior and the surroundings are fairly bright the contrast is usually too great for visual comfort. Often a simple artistic shade may be easily supplied without sacrificing the congruity of the whole and thus make the fixture satisfactory. Such frosted lamps on brackets against a dark wall often are sources of glare from which there is no escape. Many installations of this character are in existence, forming delightful harmonies with the decorative scheme when unlighted, which testifies to the artistic ability of the architect but also to his failure to visualize the lighting effect. The same may be said of some of the gorgeous glittering effects of bespangled fixtures befitting the Renaissance period. These are delightfully congruous with the surroundings when unlighted and doubtless were satisfactory in the period in which they evolved when candles of low intrinsic brightness were used, but with modern light-sources of hundreds of times greater brightness such units are very annoying. Chandeliers are often beautiful fixtures but the excessive brightnesses of modern light-sources usually make it necessary to use diffusing shades which interrupts the artist's decorative scheme. As science progresses even art must alter its traditions in order to meet the first requirement of lighting, namely, safe and comfortable vision.

In fact, the high brightnesses of modern light-sources have made it imperative to curb the traditional freedom of the artist. As long as only light-sources of low brightness such as the candle flame existed, vision was not endangered or often annoyed and the only criticism that could be applied was one of inefficiency in the use of light. This latter criticism has dwindled in importance with the modern high efficiency of light-production but the other criticisms become exceedingly important because they aim at the conservation of a human resource which is

irreplaceable and incomparable in value with cost of lighting. As much as we would like to preserve the art of the past in lighting fixtures, scientific progress in light-production makes it necessary to abandon some of it or to modify it to meet the more urgent demands of safe and comfortable vision.

In many interiors and even in some modern fixture displays, designs are found which are relics of the early days of gas flames and carbon incandescent lamps. These fixtures, consisting of curved arms supporting small glass shades oriented in various directions which confront the observer from every viewpoint, did not seriously offend vision when used with the light-sources for which they were designed. Though of doubtful artistic value most of these are now doomed to the discard on the basis of conserving vision because they are quite unsatisfactory with modern light-sources of high brightness.

One of the most important viewpoints in connection with lighting fixtures is that of the lighting effect desired or obtained from them. There are numberless designs available which give a variety of effects which may be included under the classification of direct-indirect. In the choice of a fixture two viewpoints are important from the standpoint of lighting. The first usually should be that of the lighting effect obtained with the fixture and the second that of the design, appearance, and various practical aspects of the fixture itself. A new scientific design may appear on the market and just claims are made as to its novelty, appearance, and various practical features. But claims may also be made regarding the lighting effect when as a matter of fact this may not differ materially from that obtained by simple, commonplace units that have been in use for years. This may be illustrated in Fig. 5 where the glass elements are represented by dotted lines, opaque elements by full lines, and light-sources by crosses. By various combinations of clear, diffusing, and prismatic glass the five lighting units may be made to give practically the same lighting effects, especially if the installation involves at least several units. It is fortunate that such a variety of units are available for a certain lighting effect because it extends the possibilities of

lighting by not limiting too narrowly the artistic designs and practical features of fixtures.

To further illustrate the point let us take the two-circuit fixture in which the desirable element of variety in lighting is inherent. This is diagrammatically illustrated in Fig. 6. By

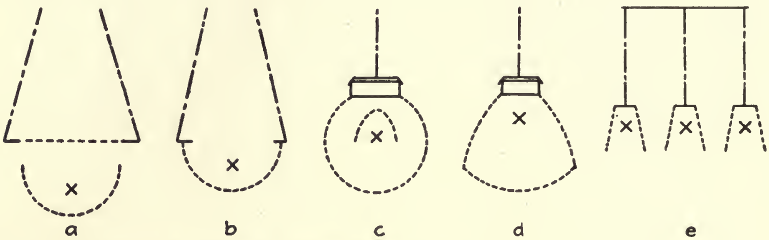


FIG. 5.—Units of different appearances which may distribute light quite similarly.

means of various kinds of glass the lighting effects in these cases may be made closely alike yet with variety in design. Three distributions of light are obtainable in each case, one from each circuit separately and a combined distribution. From

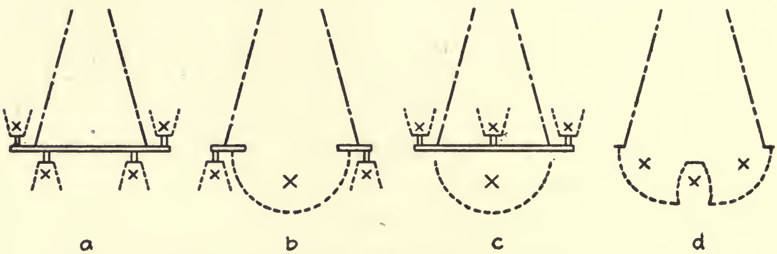


FIG. 6.—Units providing a degree of variety in distribution of light.

the symmetry of the light-sources the different circuits are readily discerned. These are only a few of the different units which may be so designed and equipped with glassware as to give approximately the same lighting effects. The number is limited only by the mechanical and artistic possibilities.

It has been the aim of this discussion to indicate the important place of fixtures in the progress of lighting practice. As a means to an end they are as important as light-sources and should be made, sold, and installed by those possessing a

knowledge of the scientific and artistic principles of lighting which are involved. A conspicuous criticism which has appeared in this discussion is that the lighting fixture is too often considered as being independent of the chief aim of lighting which is to realize a desired effect. Lighting fixtures are to be looked at but primarily their function is to distribute light; therefore their artistic design should perform the function of an artistic drapery upon the scientific design which is created or chosen for the purpose of obtaining a desired distribution of light.

CHAPTER VII

LIGHT AND COLOR

Already stated there are many advantages in the study and application of lighting in its broadest sense, in separating the analysis or problem into two parts which deal respectively, with distribution and with quality of light. In considering the former there is no need for analyzing light itself, but in order to apply the scientific and artistic possibilities of color we must delve deeper into light and study the spectrum, the physics of color-mixture, the psycho-physiology of color-vision and the psychology of color. Various chapters deal with these aspects, but before the lighting specialist is able to utilize the scientific possibilities and the charm of color to their fullest extent, he must be intimately acquainted with light itself.

The word "light" is indefinite in meaning because it is used to indicate energy as well as luminosity or light-sensation, and in this book both of these meanings are employed for the sake of convenience. The light from a tungsten incandescent lamp appears to the eye to be yellowish-white in color; that is, a tint of yellow. However, the prism or diffraction grating shows it is not homogeneous but consists of many colors. The light from the noon-day sun on a clear day is commonly considered to be white, or nearly so, but when a pencil of this white light is passed through a glass prism, a spectrum of many hues from violet to red is seen. The number of distinctly different hues which are visible in a continuous spectrum depends upon the refinement of the method of observation but may be considered to be approximately one hundred for the sake of simplicity. The most conspicuous regions of the spectrum in their order of spectral sequence are violet, blue, green, yellow, orange, and red.

A splendid analogy to the emission of radiant energy and to the perception of light is that of wireless telegraphy where we

have the sending source, the receiving station, and the electromagnetic waves which carry the message. Analogous to these we have the light-source which emits electromagnetic or radiant energy of many wave-lengths in the case of a high-temperature source such as the sun, a gas mantle, an incandescent filament or a carbon arc. The retina of the eye is the receiving station tuned to respond to a certain narrow range of wave-lengths which are included in what is termed the "visible spectrum." But each train of waves of a given wave-length produces a sensation of a certain hue distinct from that caused by a train of waves of any other wave-length. The electromagnetic or radiant energy of the shortest wave-lengths to which the visual process responds produces the sensation of violet and the longest, the sensation of deep red. Owing to their minuteness these wave-lengths are measured in terms of very small units, one of the commonest being the micron which is one-millionth of a meter or one-thousandth of a millimeter in length and is designated by the Greek letter, μ. The symbol $\mu\mu$ is one-thousandth μ or one-millionth of a millimeter.

It is unnecessary to go far into the details of the production of the spectrum for these lie in the realm of color not of primary interest here. When a pencil of sunlight is passed through a glass prism, energy of short wave-lengths is deviated more by refraction than energy of longer wave-lengths, with the consequence that the pencil is spread out like a fan on emerging from the prism, and the various trains of waves of different wave-lengths are thus separated and the spectrum results. Nature presents the spectrum of sunlight in the rainbow, the various rays of different wave-lengths being separated in a similar manner by the raindrops. When viewing such a spectrum each portion of the retina covered by the retinal image of the spectrum is stimulated by a single train of waves each homogeneous as to wave-length, with the result that the different spectral hues are seen. If a white card be illuminated by the integral light from the sun, each portion of the retinal image is being stimulated simultaneously by visible energy of all wave-lengths and, though all color-sensations are probably aroused, the integral result is a sensation of white. Thus

the eye alone cannot analyze light spectrally and the visual process is said to be synthetic with respect to color. It may be well to note at this point that, in general, the eye alone should not be trusted to estimate the spectral character or quality of illuminants or of colored media by mere visual inspection, for the color-sensation in the eye is always the integral result of all the individual color-sensations which may be due to the radiant energy of the various wave-lengths present in the illuminant or reflected or transmitted by colored media.

In the study of illuminants and of colored media the spectral analyses are generally recorded in terms of energy of various wave-lengths. However, the eye is not equally sensitive to energy of various wave-lengths. It is most sensitive for energy producing the sensation of yellow-green, which lies in the middle of the visible spectrum, and the sensitivity decreases rapidly toward the ends of the spectrum. The visibility of radiant energy of various wave-lengths has long been a subject of research, yet even today these visibilities have not been established precisely; that is, the results of different investigators do not exactly agree.

It is out of the question to discuss the many aspects of the science of color in a book devoted to lighting. These have been treated elsewhere[1] but a glimpse of a few of the chief aspects will be attempted here in order that following chapters may be more easily understood.

From the viewpoint of color in lighting the spectral characteristics of illuminants are of primary interest. Light-sources which radiate energy owing to their high temperature are found to exhibit continuous spectra; that is, if the temperature is sufficiently high, radiation of all visible wave-lengths is emitted. Until a color-temperature nearly as high as that of the sun is reached, energy of the longer wave-lengths predominates and as the temperature of the sun is not reached in any light-sources available at present, all illuminants of this character are yellowish in color. For example, if a rheostat be placed in series with a tungsten lamp it will be found that current may be passed through the filament without heating it sufficiently to

[1] M. Luckiesh: "Color and Its Applications," D. Van Nostrand Co., 1915.

make it glow. If the experiment is performed in a dark room, it will be found on increasing the current sufficiently that the filament will begin to glow a deep red in color. At this point the radiation emitted consists almost entirely of red rays. As the temperature is increased the filament becomes brighter and the color changes to orange indicating that energy of shorter wave-lengths is being emitted although the red rays still predominate. The integral sensation caused by the simultaneous stimulations of the retina by the radiant energy of various wave-lengths is an orange tint. The filament may be increased in temperature until it melts, yet at no time does the integral color of the light appear white if compared with noon sunlight because the melting point of the tungsten is far below the temperature necessary to produce white light. The yellowish color indicates that the rays of longer wave-length predominate at all temperatures at which the tungsten may be operated. This is also true of the crater of the carbon arc and of other artificial illuminants emitting light by virtue of their high temperature as this is ordinarily considered. The progress in light-production by heating substances to a high temperature has been toward higher temperatures because of the higher luminous efficiencies obtainable and the progress in color has been with the filament lamps for example, from the yellow light of the carbon lamp to the yellowish-white of the tungsten lamps.

Incandescent gases emit discontinuous spectra usually in the form of narrow lines or bands in various regions of the spectrum. These spectra are always characteristic of the elements or gaseous compounds and this fact has formed the basis for spectrum analysis so valuable in chemistry. The flames of arcs and the mercury-vapor lamps emit line spectra; the visible spectrum of the latter consisting chiefly of lines of wave-lengths 0.408μ, 0.436μ, 0.546μ, and 0.578μ being respectively violet, blue, yellow-green, and yellow in color. The different elements with which carbons are impregnated are chiefly responsible for the various colors obtained from the flaming arcs. The Moore nitrogen tube emits light of a pinkish color which is the integral color of the combined color-sensations due to the line-spectrum of nitrogen. The carbon-dioxide vacuum tube emits

a line-spectrum containing a great many lines and the integral color as well as the spectrum itself closely approximates an average daylight consisting of a mixture of direct sunlight and skylight. Many different colored lights may be obtained by

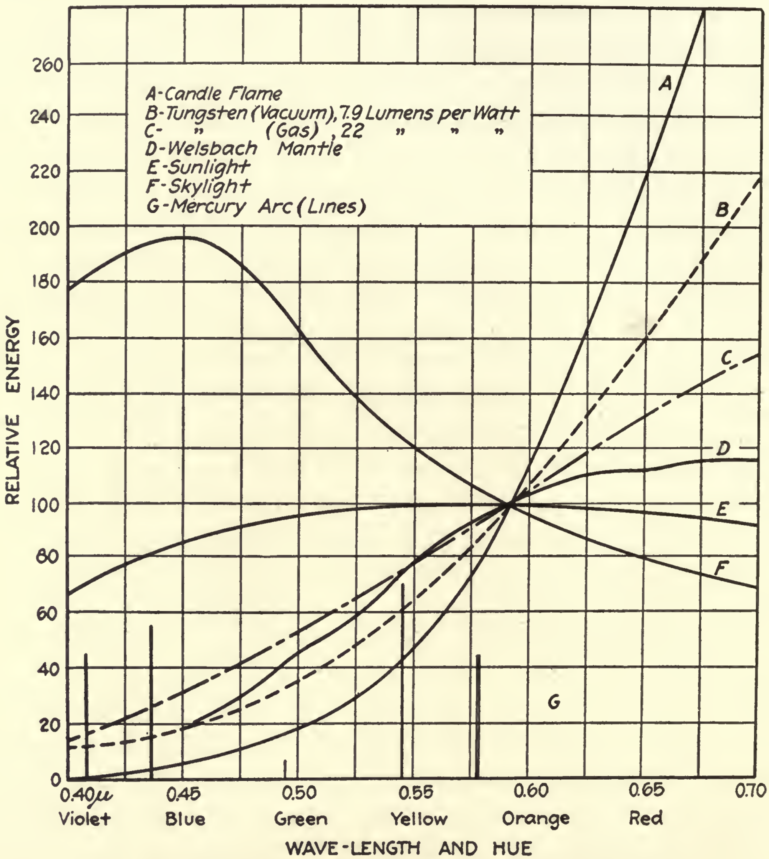


FIG. 7.—Distribution of radiant energy in various spectra.

electrically exciting various gases and beautiful effects are thus possible although such light-sources are not very practicable at the present time. It is possible that the future may witness developments along this line and the production of a wider variety of colored lights directly from the light-source.

In Fig. 7 are shown the spectral energy-distributions of a

number of common illuminants plotted, for the sake of comparison, to equality near the middle of the spectrum. Various points in the foregoing discussions are exemplified in the figure. The short vertical lines indicate the spectrum of the mercury arc. In general, the predominance of radiant energy of the longer wave-lengths or yellow, orange, and red rays in artificial illuminants is to be noted.

The next important aspect of color in lighting is the effect of the illuminants upon the appearance of a colored object. It may be taken as a fundamental axiom that a colored object will not appear the same, in general, under two illuminants differing in spectral character. A red fabric appears red under daylight or under a tungsten lamp because it has the ability to reflect the red rays and to absorb all or nearly all of the other colored rays. But the color of the red fabric depends upon the illuminant because, for example, it will appear black or a brownish-black under an ordinary mercury arc. In a preceding paragraph the wave-lengths of the important lines in the spectrum of a mercury arc are given and it is seen that no red lines appear. If the illuminant emits no red rays and the red fabric reflects no other rays, it is obvious that it will appear black because the luminosity of a reflecting medium is due to the visible radiant energy which is reflected by it toward the eye. The energy which is absorbed disappears as radiation and is generally converted into heat.

There are some characteristics of colored media which should be of interest to the lighting specialist. Some dyes and other substances have the property of fluorescence or phosphorescence, the former being a momentary phenomenon as distinguished from the persistence of the latter. Usually these phenomena are excited by ultra-violet energy and that of the short visible wave-lengths but the light which is emitted generally bears no resemblance in color to that of the exciting light. Such a fluorescent dye as rhodamine appears red when illuminated by the radiation from a mercury arc because it absorbs energy of short wave-lengths and emits energy of long wave-lengths. This phenomenon has been taken advantage of by Dr. Hewitt and applied to the mercury-arc unit in the form of

a dyed reflector thus adding red rays and thereby reducing the distortion of colors under the light from the mercury arc.

Although no certain estimate of the spectrum of a color can be made by the eye alone, it may be helpful to indicate in a general manner the spectral colors which will be found in the light reflected or transmitted by ordinary colored media such as pigments, dyes, and glasses most commonly encountered.[1] These are indicated below by means of six spectral hues, it being understood that the hues lying between these in the spectrum are also present and that the analyses are only roughly approximate.

APPROXIMATE SPECTRAL CHARACTERS OF A FEW COLORS AS COMMONLY ENCOUNTERED

Violet—violet, blue, some green, and often deep red.
Blue—violet, blue, green, and often deep red.
Green—blue, green, and yellow.
Yellow—green, yellow, orange, and red.
Orange—yellow, orange, and red.
Red—orange, red, and sometimes deep violet.
Purple—red, violet, and blue.

Colored media which are ordinarily available rarely exhibit colors of high purity or saturation, the dyes and glasses usually being more satisfactory in this respect than pigments.

At this point it may be helpful to outline roughly the hues of the spectrum in relation to wave-length, it being understood that these divisions are only roughly approximate.

THE APPROXIMATE DISTRIBUTION OF COLOR IN THE SPECTRUM

Violet	limit to 0.43μ
Blue	0.43μ to 0.47μ
Blue-green	0.47μ to 0.50μ
Green	0.50μ to 0.53μ
Yellow-green	0.53μ to 0.56μ
Yellow	0.56μ to 0.59μ
Orange	0.59μ to 0.62μ
Red	0.62μ to limit

The limits of the visible spectrum vary with many conditions and with different persons. For most practical purposes the

[1] The spectral characteristics of many pigments, dyes, and glasses will be found in a paper by the author on "The Physical Basis of Color-Technology," *Jour. Frank. Inst.*, vol. 184, p. 73, 227, 1917.

limits are 0.4μ to 0.7μ but it is usually possible under intense illumination to experience the sensation of light from radiant energy of any wave-length between 0.39μ and 0.78μ.

Although the light-sources available at present differ considerably in color they do not present a variety of colors pure enough for producing many color effects either artistic or spectacular except in special cases where they are peculiarly adaptable. Furthermore, these colors are usually quite accidental as determined by the exigencies of industrial practice or economy, and do not provide tints which may be harmoniously blended for artistic purposes in ordinary interiors. They have been utilized in special cases with excellent results, for example, by Mr. Bassett Jones at the Allegheny County Soldiers' Memorial and by Mr. W. D'A. Ryan at the Panama-Pacific Exposition. But for most requirements it is necessary to modify an illuminant by means of colored screens in order to obtain the desired effects. In such cases a knowledge of the spectral characteristics of colored media is applied in making a colored lacquer, colored glass or other suitable filter.

It is comparatively simple to produce the required color if permanency is not a factor. Where this is important and the correction is one such as is required in producing artificial daylight, the problem must be attacked from the scientific side and the spectral analyses must be made with apparatus which is analytical. In many cases where merely the subjective color is of importance the eye alone suffices and the proper tint may be readily obtained by a knowledge of color-mixture and an acquaintance with colored media.

By the use of colored filters two illuminants may be obtained which appear exactly alike to the eye in integral color though spectrally they may be very different. For example, two illuminants may appear white though the spectrum of one may differ very much from that of white daylight; in fact, the light from the quartz mercury arc appears nearly white but its spectrum consists of only a few lines making it quite unfit for general color work. In a similar manner two yellows may appear exactly alike to the eye yet one may not contain any spectral yellow at all because green and red light when properly mixed will produce a yellow.

It has been indicated in a previous paragraph that the color of an object depends upon the spectral character of the illuminant. That this is true may be readily proved by viewing any colored object alternately under two different illuminants. Those illuminants which have discontinuous spectra distort colors in general very much more than those having continuous spectra. The variation in the appearance of a colored object under different illuminants is due largely to the impurity or lack of saturation of ordinary colors for, if colored media were of spectral purity, the variation in their appearance under different illuminants would be confined to changes in brightness only.

A mental picture of the influence of the illuminant upon the appearance of a color is obtained by considering the effect on the entire range of tints and shades. Tints of a certain hue vary from complete saturation (spectral purity) to complete unsaturation (white). As already stated colors of spectral purity (which do not exist among colored media) would only be altered in relative brightness by different illuminants. Whites assume the integral color of the illuminant so that certain tints lying between these two extremes are maximally influenced in appearance by the spectral character of the illuminant. To choose a color which will be most changeable in appearance under different illuminants requires experience and an acquaintance with many facts of color science. Medium or light tints are in general greatly influenced by the illuminant. Purples are excellent examples and the reader will find it of interest to study the reasons for the changes in appearance by referring to Figs. 7 and 9.

If the spectral characteristic of a pigment, for example, extends over quite a range of wave-lengths it is seen on referring to Fig. 7 that there will be a different distribution of the various colored rays in the light reflected under two different illuminants. Under such artificial illuminants as the tungsten lamp, kerosene flame and some gas mantles, most colors will appear "warmer," that is, more yellowish or reddish than under sunlight. Under skylight they will in general appear more bluish than under sunlight. Under some of the gas mantles which emit a light of a greenish tint the greens will be accentuated and many colors will appear more yellowish in color. Under

illuminants having discontinuous spectra such as the mercury-vapor lamps, the colors will be more distorted and it is more difficult to predict the change. The following are approximate appearances of a few colors under different illuminants but these will not hold strictly for all colors of the same appearance to the eye under a given illuminant, because of the variations in spectral character of colors which are possible without a change in the appearance of the colors under the given illuminant.

The Influence of the Illuminant on the Appearance of Colors

Colored media	Blue skylight	Noon sunlight	Tungsten lamp	Mercury arc
Ultramarine	Blue	Greenish-blue	Darker ruddy blue	Deep blue
Chrome yellow	Lemon yellow	Golden yellow	Orange-yellow	Greenish-yellow
Vermilion	Yellowish-red	Brick red	Red	Ruddy gray
Chrome green	Green	Yellowish-green	Yellow-green	Yellowish-green
Cobalt blue	Light blue	Light blue	Violet	Violet blue
Purple	Blue	Reddish-violet	Red-purple	Violet
Pink	Pink	Redder pink	Light red	Light blue
Dark blue	Blue	Blue	Bluish-black	Violet blue

The appearances of pigments, dyes, and glasses are so varied and depend upon so many factors that it appears best to recommend that experience be gained by actual experiment. It is difficult to describe the changes in color even in specific cases but it is easy to see the magnitude of these changes by arranging a series of compartments illuminated by common illuminants. By viewing specimens of the same colored fabric simultaneously, the importance of the illuminant will be found to be very great. Studies of the effect of intensity in distinguishing colors also may be carried out. Such a demonstration is extremely edifying to the user of light.

A great deal of confusion arises in dealing with color from the inaccurate and indefinite terminology ordinarily used. Before proceeding further in the discussion of color it is necessary to define the terms to be used. For most scientific purposes it is essential to use the results of spectral analyses but a terminology for everyday use need not include terms for indicating the spectral characteristics of colors. Ordinarily we are concerned with subjective color, that is, with its appearance to the eye, so the

most practicable terminology will provide terms which will give an idea of the appearance of colors.

It has been found that all colors except the purples (which include pink, rose, and others having dominating components of red and violet) may be matched by mixing monochromatic spectral light with white light. Purples, for which no match in hue is found in the spectrum, may be analyzed by the same process except that a complementary hue is mixed with a purple until the mixture matches the standard white light. On the basis of this method of colorimetry it is possible to define a color in terms of hue, saturation or purity, and luminosity or brightness. These are more specifically defined below along with other terms.

Hue is that property of color by which the various spectral regions are characteristically distinguished. All colors except purples and white may be matched in hue with spectral colors. In the case of a purple the spectral hue which is complementary to the hue of the purple is ordinarily used for scientific designation. It is recognized that hue is commonly designated or implied in the names of colors.

Two hues are complementary if they may be mixed to produce white. White may be considered to be a color possessing no hue. By mixing two or more hues, properly chosen both as to hue and intensity, white may be obtained. Whenever two or more hues are mixed the resultant color, though it may still have a dominant hue, will usually appear as having an admixture of white. It is interesting to arrange the spectral colors in proper sequence upon three-fourths of the circumference of a circle and to close the gap by means of the purples. If this is properly done the colors which lie at the opposite ends of any diameter are approximately complementary. As an aid the following pairs of approximately complementary colors are given.

Complementary Hues

Violet and yellow	Blue-green and red
Blue and orange	Green and purple

With these as reference points on the "color circle" other complementaries will be readily found.

Saturation of a color is its degree of freedom from admixture with white. Monochromatic spectral light may, for purposes of physical measurements, be considered as having a saturation of 100 per cent. As white is added the saturation decreases, until when the hue entirely disappears the saturation is zero. White is the limiting color having no hue and zero saturation.

Tints are produced by the addition of white to pure colors. Thus rose is a tint of purple; cream is a tint of yellow; and the clear sky has a tint of blue.

Brightness or *luminosity* of color needs no special definition but rather an explanation in its relation to color. It is that which a totally color-blind eye sees. With colors we are seldom concerned with absolute values of brightness but relative luminosities are important. For example, white is only relative with respect to luminosity or brightness for if another specimen of the same material be illuminated to a lower intensity it will appear gray though the first appears white. However, if the second specimen is illuminated to a higher intensity the first will now appear gray by comparison instead of white. This is true of the luminosity of any color. With pigments the luminosity may be reduced by an admixture of "black." An excellent term which describes the brightness is "*value*" in the sense used by the artist.

Shades of a color are produced by lowering its brightness which may be done by decreasing the intensity of illumination or by the admixture of "black" in the case of pigments. For example, olive green is a shade of yellow-green.

It is obvious that for a given hue the saturation and brightness may be altered separately or together thus producing a vast number of colors. The total number of colors in the broadest sense including the element of brightness, that may be distinguished by the human eye may be estimated only approximately. Inasmuch as only the order of magnitude would be of interest here, we will set the limits rather wide, namely between 100,000 and 1,000,000. Leaving luminosity out of consideration it is likely that the eye can distinguish at least 5000 different tints under the best experimental conditions.

CHAPTER VIII

COLORED ILLUMINANTS

Colored illuminants for lighting effects may be divided into two broad classes; namely, fairly pure colors of high saturation, and tints of low saturation. The purer colors have many uses in spectacular illumination, stage effects, advertising displays, signalling and other scientific applications. The tints are chiefly applicable for artistic purposes and it appears that the future will witness a wide application of tinted illuminants as these become more readily obtainable and as the charm of tinted light becomes more appreciated. The mistake is often made when employing colored light for artistic purposes that the hue is too pronounced for it should be felt rather than seen. The chief deterrent to the wider application of color in lighting is the difficulty of obtaining the desired colored light for usually it is necessary to obtain colored media and to adapt them to the light-source or accessory.

The sources of colored light for illuminating purposes are commercial illuminants unaltered or equipped with colored media. The commercial illuminants afford a wide variety of tints but for practical considerations many of these are barred from the greater field in interiors where the charm of colored light is beginning to be appreciated. Before discussing the various methods and colored media available for obtaining colored light for illuminating purposes it appears of interest to discuss the colors of common illuminants and a few special ones which may find greater applications in the future.

Daylight.—Clear noon sunlight may be taken as a standard white light for the present purpose, although this is an unsettled point. The physiologist and psychologist sometimes base the determination of white light upon different criteria than does the physicist. However, clear noon sunlight will be considered as having no hue and zero saturation. Satura-

tion will be expressed in per cent., and is equal, in a given case, to 100 per cent. minus the per cent. white which must be added to a spectral hue in order to match the given illuminant in color. Owing to the lack of standardization of white light, saturations of colors are not well established so the values in the following descriptions will be presented in round numbers which represent only the approximate values. Clear blue skylight, which is selectively scattered sunlight, has a saturation of approximately 50 per cent. and its hue is near 0.47μ. That is, a mixture of about 50 per cent. of monochromatic light of wave-length 0.47μ and 50 per cent. of white light produces a light which matches clear blue skylight in color. The means for imitating daylight in spectral character are described in another chapter but these provide illuminants which simulate daylight both objectively and subjectively; that is, in spectral character as well as in integral color as it appears to the eye. Only subjective color-matches are considered in the present discussion.

Electric Incandescent Filament Lamps.—These illuminants range in color from a deep yellowish tint for the old "4-watt" carbon lamp to a yellowish-white of the modern lamps. The saturation of the "4-watt" carbon is about 80 per cent., and its hue about 0.595μ. These values for the tungsten vacuum lamp (8 lumens per watt) are respectively about 70 and 0.590μ; and for the gas-filled tungsten lamp (22 lumens per watt) are about 55 and 0.585μ. It is seen that the hue as expressed in wave-length of spectral light varies only slightly for these lamps but the saturation varies considerably. A decrease in saturation indicates an approach toward white, for white is of zero saturation.

Candle Flame.—Its saturation and hue are respectively about 85 per cent. and 0.60μ. This is a very pleasing color for many interiors where daylight appearances of colors are not important and it may be obtained very readily and without an excessive decrease in luminous efficiency by tinting a tungsten lamp as will be described later.

Mercury Arc.—The color of the light emitted by the glass-tube arc is represented by a saturation of about 25 per cent.

and a hue (blue-green) of about 0.49μ. The quartz mercury arc is nearly a subjective white approaching zero saturation.

Acetylene Flame.—The saturation of the light from an acetylene flame is nearly the same as that from a tungsten vacuum lamp operating at 8 lumens per watt, its hue being in the neighborhood of 0.585μ.

Vacuum Tubes.—The Moore carbon-dioxide tube emits a light which is a close approximation to the ordinary mixture of skylight and direct sunlight. The nitrogen tube emits a pink light of moderate saturation; the helium tube a yellowish light of about 60 per cent. saturation and a hue close to 0.59μ; the neon tube a light of a decided orange hue, about 0.62μ, and of high saturation of the order of magnitude of 90 per cent.

Carbon Arcs.—These illuminants vary widely in color owing to the various metals contained in the impregnating salts. The crater of the pure carbon arc emits a light of a hue in the vicinity of 0.58μ depending upon the current density. The saturation is of the order of magnitude of 40 per cent. The purplish tint of the pure carbon arc is due to the arc and not to the crater for the latter is yellowish-white. The yellow flaming arc emits bands of green and red light (due to calcium) superposed on a weaker continuous spectrum. Its color is a pronounced yellow. The snow-white flaming arc, whose carbons are impregnated with rare-earth compounds, and is said to emit a light which approximates a mixture of skylight and direct sunlight. The red flaming arc emits light of a pinkish-red color due chiefly to the yellow and red spectral lines emitted by strontium with which the carbons are impregnated.

Gas Flames and Mantles.—The color of the light from a gas flame varies somewhat but is found in the neighborhood of a kerosene flame. The light from incandescent mantles varies widely in color from a greenish to a yellowish hue.

Various transmitting and reflecting media are available for altering the color of illuminants by absorbing some of the spectral colors. Among these, colored glass is the most permanent medium and is available in various forms. Sheet glass may be obtained in a variety of colors but many of these have not been made specially for illuminating purposes so that

some manipulation is usually necessary. Signal lenses afford a variety of moderately pure colors for special purposes, among the available colors being red, yellow, canary, green, blue-green, blue and purple. The red is usually sufficiently pure for the most exacting requirements of lighting, and the yellow and canary are also usually satisfactory. The green may be used successfully for many purposes for which it may be required but it may be altered toward a yellow-green by superposing upon it a canary or yellow glass. Similarly, it may be altered toward a bluish-green by superposing a blue-green glass. The blue glasses are ordinarily unsatisfactory for some purposes owing to the fact that the cobalt blue, which is most common, transmits deep red rays. These may be eliminated by superposing a blue-green (copper) glass. Purple has few uses in lighting but pink is often desirable. A beautiful pink glass is obtainable by incorporating gold in glass. Further possibilities in combining colored glasses may be realized from a knowledge of the principles of color which are involved.[1]

Glass caps are available in several colors and some incandescent lamps are made with colored glass bulbs, among them being red, yellow, canary, green, and blue. Future demands will doubtless result in the availability of purer colors and various tints.

Illuminating glassware provides some possibilities for obtaining colored light especially the deep glass shades and enclosing units which are colored. If a tinted light is desired for general illumination an enclosing unit is usually essential. Even with the pendant shades and inverted glass bowls beautiful effects may be obtained by so devising the unit that the light which is tinted by transmission through the colored glass will fall on the desired places and the unaltered light which escapes directly will serve the purpose of general illumination. A reverse effect is obtained in such a case as a shower equipped with yellow pendant shades. If this is placed over a dining table the faces of the diners and the surroundings are lighted by

[1] M. Luckiesh: "The Physical Basis of Color-Technology," *Jour. Frank. Inst.*, 1917, vol. 182, p. 73, 227.

the warm tint and the predominant light on the table is unaltered in color.

Silk and other textiles are readily obtained of suitable colors and may be applied to lighting units with ease. These not only may be selected to harmonize with the decorative color-scheme but the light transmitted and reflected by the colored fabric lends the charm of color so enjoyable in many interiors.

Colored gelatines are also available in a vast variety of tints but these are not very permanent in color. They will not fade very rapidly under exposure to moderate intensities of illumination but deteriorate rapidly if allowed to become hot. The yellows are in general the least fugitive.

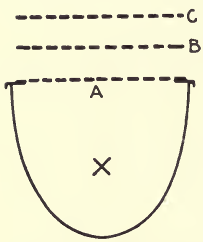


FIG. 8.—Method of increasing the life of colored screens.

Colored lacquers for dipping lamps are available in a variety of colors including pink, red, deep amber, canary, green, blue-green, and blue. Their chief disadvantage is lack of permanency but they are less fugitive under exposure to moderate light if the temperature is not too high than when exposed to intense heat and light. The coloring elements are usually dyes as is true of the gelatines. It is often advantageous to use these dyed gelatines or lacquers on glass or mica separated from the light-source by an air-space. A clear glass may be interposed between such colored filters and the light-source which, by absorbing some of the infra-red energy and by providing an air-space, greatly prolongs the life of the colored filters. A refinement of this scheme is to use in place of the clear glass a colored glass of almost the desired color. This absorbs even more of the undesired energy than clear glass, and the dyed filter may be depended upon only for the final color-correction. One scheme is shown in Fig. 8 where *A* is a heat-resisting glass, *B* is the colored glass of approximately the desired color, and *C* is the final correcting filter in which comparatively fugitive dyes may be used with fair satisfaction. A water-cell is very effective in absorbing the infra-red energy and therefore has been used for such purposes.

An advantage of colored lacquers is that they may be readily mixed, diluted, and applied, thus affording an easy means for obtaining many desired colors of light. Many red dyes in weak concentrations are pink in color so that a red lacquer may be diluted with uncolored lacquer in order to obtain pink. It is well to distinguish between the clear lacquer and the thinner or solvent. If the latter is used the lacquer may become so dilute as to lose its binding qualities. Many of these lacquers consist of a solution of celluloid in alcohol, ether, amyl acetate, acetone, etc., but generally they are not weather-proof. Varnishes withstand the elements outdoors fairly well and shellac has value as a lacquer for dyeing. Solutions of yellow dyes of low concentrations are generally greenish-yellow in color so that if a warm tint of yellow, which simulates the old illuminants, is desired an addition of pink is necessary. This absorbs rays in the middle of the spectrum, namely in the yellow-green region. Green lacquers which do not transmit red rays are relatively rare. Those which transmit a deep red band may be corrected to a satisfactory green by adding blue-green dye provided the blue-green does not transmit these red rays. Moonlight is usually simulated by using a greenish-blue filter of a fairly unsaturated tint over such an illuminant as the tungsten lamp although the spectral character of moonlight in reality closely approximates that of sunlight. This "moonlight" blue may be made by mixing weak solutions of blue and green or by adding blue to an unsaturated blue-green lacquer. Solutions of blue dyes which do not transmit deep red rays are very rare but usually a fairly satisfactory deep blue filter may be made by adding blue-green to the blue lacquer. Purple may be obtained in any depth of color by adding pink and blue to a clear lacquer. Many dilute reds provide satisfactory pinks.

Many pigments are quite permanent but these are insoluble and are more difficult of application. The author has used these successfully for some purposes by developing a special method of application. Tinted light may be obtained by selective reflection from colored surfaces and for this purpose pigments serve very well. For example, the inner surface of an opaque reflector may be colored with a paint made by suspend-

ing the pigment in a suitable vehicle. Where the surface is not exposed to intense heat, varnish, shellac, and celluloid lacquer are satisfactory. Such pigments may be applied to any surfaces which may be depended upon to supply the colored light by selective reflection but a rough surface is best.

For temporary lighting effects even aqueous solutions of dyes, metallic salts, etc., find application and beautiful effects may be obtained by permitting colored salts to crystallize on transparent or translucent surfaces. Gelatine filters may be made by dissolving a dye in a warm 6 per cent. aqueous solution of gelatine. This colored solution may be flowed upon level glass and when dry excellent color filters are available. Colored lacquers may also be flowed upon level glass and allowed to dry. If a diffusing colored screen is desired it is possible to dye an opal lacquer or a temporary filter may be made by dyeing a warm saturated aqueous solution of epsom salts. After the latter has dried upon glass an effect similar to frosted colored glass is obtained. This will not withstand heating because the crystals will fuse at a moderate temperature. These are some of the ways of devising filters for obtaining light of desired colors which have been found useful by experience.

For obtaining daylight effects various units are available which simulate in spectral character, north skylight, noon-sunlight, and approximate sunlight. These are discussed in a separate chapter owing to their wide application.

Light of any desired color may be obtained by applying other methods of color-mixture. In preceding paragraphs of this chapter it has been shown how an illuminant could be altered by selective reflection and transmission. In order to apply this subtractive method with certainty as to the results, knowledge must be had of the spectral characteristics of the colored media and of the color which remains when certain colored rays have been subtracted or absorbed. An inexpensive pocket spectroscope is a valuable aid in such work and adds much to the interest in the application of color to lighting.

It is helpful in obtaining colored light by the subtractive method, that is, by superposing colored glasses, mixing colored lacquers, etc., to consider the primaries to be purple, yellow,

and blue-green. Such combinations or mixtures transmit only those colored rays which they transmit in common. For example, a purple filter superposed on a yellow one results in a red filter; a mixture of yellow and blue-green paints results in green paint; and a blue-green glass superposed on a purple one results in a violet or blue transmission. If the spectral curves be drawn for these subtractive primaries the subtractive method is seen more clearly. These are shown diagrammatically in Fig. 9 where the vertical heights of the full lines represent spec-

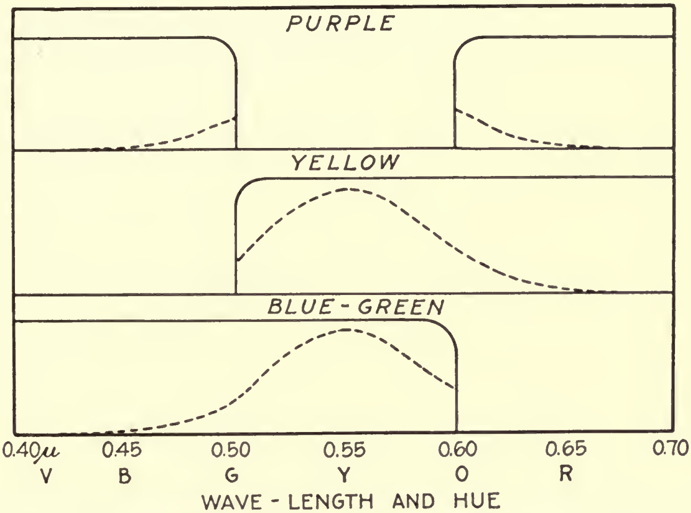


FIG. 9.—Diagrammatic illustration of 'subtractive' primary colors.

tral transmission- or reflection-factors for energy of various wave-lengths. The dotted lines represent the corresponding spectral luminosities for a given illuminant. It is easy to note the rays which any pair transmit in common and that the three superposed result in zero transmission. From a study of this method it should be possible to employ any colors in subtractive mixtures with a fairly definite prediction as to the results to be expected. If illuminants possessing continuous spectra are used the table of complementary colors and the "color circle" presented in Chapter VII will be found helpful in predicting the results of selective absorption. The best way in which to acquire a general knowledge of the manipulation of colored

media is by experience with them and the subject should be sufficiently interesting and attractive to pursue with pleasure. An extensive treatment of color and its applications has recently been published[1] for those who wish to go deeper into the subject and to avail themselves of the manifold possibilities of color in lighting.

It has long been known that, by mixing three primary colored lights, namely red, green, and blue, any desired hue may be obtained. Although this fact has been known to

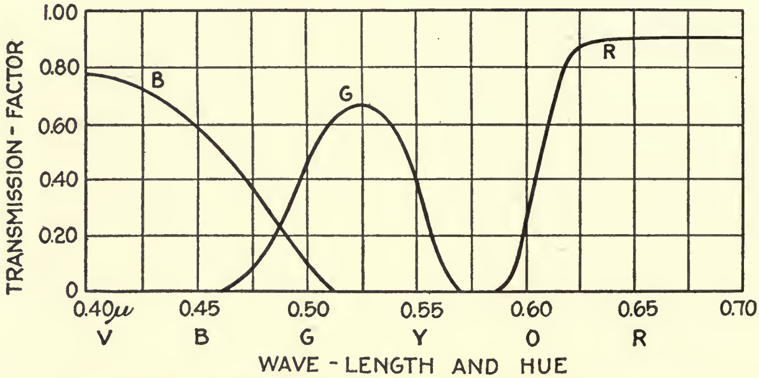


FIG. 10.—Spectral characteristics of three practicable 'additive' primary color-screens.

science for many years, it has been rarely applied in lighting effects. Its widest field of application is in stage-lighting and in spectacular effects though it has many other applications, some of which have been mentioned in other chapters. Various sets of these primary colors are satisfactory for most purposes, but the author has found the following to be very generally satisfactory for lighting effects:

A red light whose spectral limits are about 0.60μ and the end of the visible spectrum, and whose dominant hue is near 0.66μ. This is a fairly saturated red.

A green light of a yellowish tinge whose spectral limits are about 0.46μ and 0.57μ, and whose dominant hue is near 0.54μ.

A blue light which contains no red rays, whose spectral

[1] M. LUCKIESH: "Color and Its Applications," 1916.

limits are about 0.51μ and the end of the visible spectrum, and whose dominant hue is near 0.45μ.

The special transmission-factors of three colored media in the filters employed satisfactorily for many lighting effects are shown in Fig. 10. These were chosen for practicability as to transparency, permanency, ease of reproducibility, as well as to color. They are obtained by dyeing lacquers but it is hoped that they will be available eventually in glass. It is possible to obtain satisfactory combinations of colored glass in the market for producing these primary colored lights but difficulties must be overcome in combining them and in using them in a practicable manner. Quite a variety of saturations of two different hues are obtainable from mixtures of two complementary colored lights. Although the variety of colors is limited, this procedure finds applications in lighting.

The simplest means of mixing colors in this manner is usually by rheostatic control although the color of the light emitted by the light-source changes with the current and therefore the primary colors are altered. However, the change in the latter is comparatively slight and usually unimportant. Movable templates are simple expedients which may be utilized. These methods of control are discussed in another chapter.

Another method of mixing colored lights for obtaining desired tints is to juxtapose the filters or to arrange them in checkerboard fashion. For example if a "warm" yellow tint is desired it is almost impossible to obtain this by means of a single coloring element and an ordinary illuminant because such yellows are usually amber in color which in the lighter tints is a greenish-yellow. Dense amber has a dominant hue in the yellow region of the spectrum but it is of high saturation. If a few pieces of dense amber glass be placed upon a diffusing uncolored glass, the resultant light from a tungsten lamp or similar illuminant will be of the desired warm yellow hue. The resultant light consists of a mixture of the unaltered light with the deep yellow light. The diffusing glass mixes the lights so that the effect is uniform if the receiving areas are sufficiently distant. Various tints may be obtained from the ordinary colored glasses which are available.

Another example is that of a rose tint which may be obtained by placing small pieces of blue and red glass over the diffusing glass. The saturation of the resultant colored light is controlled chiefly by varying the percentage of the area of the diffusing glass not covered by the pieces of colored glass, and the hue by varying the relative areas of blue and red glasses. The method is simple as shown in Fig. 11. These checker-board filters may be used as shown in Fig. 8 in order to prolong their life if the coloring material is not permanent. Daubs

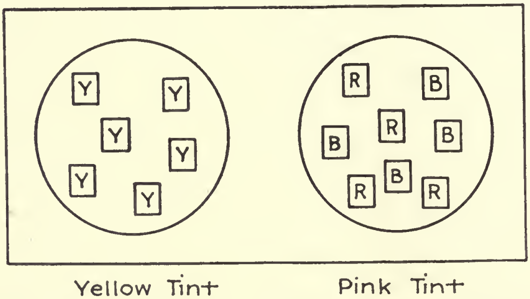


FIG. 11.—Simple method of obtaining desired tint of light

of different colored lacquers upon diffusing glass are equally effective but not as permanent. Heat-resisting glass which has been sand-blasted, on both sides if necessary in order to obtain sufficient diffusion, may be advantageously utilized for such purposes.

The principles of color-mixture with which the lighting specialist should be acquainted have been discussed in this chapter and many practicable means of utilizing colored media have been presented. The lighting specialist today usually must gather the materials for obtaining colored light and have the apparatus constructed. There is some stage-lighting and other equipment available for a few applications but the future will doubtless find that lamps and accessories will be available in greater variety for applying colored light.

CHAPTER IX

THE PSYCHO-PHYSIOLOGY OF COLOR

There are so many variables in the problems of color in lighting that no simple rules of procedure can be formulated and therefore it is necessary for the lighting specialist to be acquainted in a general manner with various aspects of color. Some phenomena in lighting remain mysteries and opportunities for achievements are lost to those unacquainted with the physiological and psychological aspects of vision and with the effects of brightness and color upon the human organism. No attempt will be made to describe the various theories of color-vision or to explain many of the phenomena encountered in the use of colored light because this would lead far afield. However, some of the more important aspects will be touched upon in order that those interested in lighting may be aided in seeking explanations from those sources which are devoted specifically to the treatment of the questions involved.

The importance of color-vision is not comparable with that of colorless-vision because the totally color-blind person is not greatly handicapped in pursuing the ordinary activities of life except those in which man has used color for special services. However, color-vision is a wonderful gift capable of adding to the variety of our experiences and, having this faculty, it should be utilized not only for technical purposes but for adding to the interest and charm of our surroundings. Many hypotheses of color-vision have been advanced but none is in complete accord with experimental data, although the latter may be at fault. Nevertheless the attention of scientists is directed chiefly toward two hypotheses, namely, that of Young-Helmholtz and that of Hering. The former, which was founded largely upon the physical basis of color-mixture, assumes the presence of three processes. It is supposed that these are responsible for red, green, and blue sensations respectively,

and that any color is the result of simultaneously arousing these three sensations of different degrees quite analogous to the results of mixtures of the three primary colors.

The Hering theory is based more upon a psychological foundation, the chief fact being the conspicuousness of red, yellow, green, blue, white, and black. Three processes are assumed to exist, each accounting for one of the following pairs of color-sensations, namely red and green, yellow and blue, white and black. There is no anatomical evidence available as yet which indicates the existence of the three processes required by either of the foregoing hypotheses but Von Kries, from such evidence, advanced the "rod and cone" theory which is supported very well by many experimental observations. Minute "rods" and "cones" are found to exist in the retina and the former are apparently responsible for achromatic sensations at low intensities. The cones seem to be responsible for both achromatic and chromatic sensations at higher intensities but appear to cease to function at twilight intensities. Although this theory explains certain visual phenomena very nicely, it does not attempt a broad explanation of color-vision as does either of the other hypotheses already mentioned.

The hypotheses of Ladd-Franklin and Edridge-Green, as well as others, are worthy of consideration but a discussion of theories of color-vision is beyond the scope of this volume. The chief object has been to warn those not particularly acquainted with the subject that there are many hypotheses, none of which is accepted completely, so that they may not be bound too closely to any one of them at the present time.

Perhaps the most important aspect of color is that of contrast. In fact, contrast in hue is the life of color and the absence of it is practically fatal. For example, if a red spot be surrounded by white, the red is much less striking than when surrounded by green. Furthermore, when a room is lighted with a colored light of high saturation there appears to be a variety of shades of approximately the same hue. There is little life to the colors and gradually the impression of color dwindles. But when the illuminant is changed to one emitting rays of all visible wave-lengths, the different colors spring into

life and their contrasts mutually reinforce each other. Owing to these contrasts the scene becomes alive with color.

The phenomenon of simultaneous contrast may be divided into two parts, namely, hue-contrast and brightness-contrast. These two are usually operating simultaneously so that it requires close analysis and experimentation to diagnose a given case. When a medium shade, such as gray, is viewed on a dark background it appears to be a much lighter shade than when viewed upon a white background. Usually when two colors are juxtaposed they appear to move farther apart in hue than when separated and viewed successively. When a color is viewed against a white background or *vice versa*, there is generally induced in the white ground, a tint which is approximately complementary to the inducing color.

In the case of juxtaposed colors the phenomenon of successive contrast appears; that is, the effect upon the appearance of a color of viewing another color immediately before. Usually the effect is to enhance the appearance of colors. Such a condition always exists when the eye is roving over any scene but it is easier to note the effect with bright and fairly pure colors. After viewing a color for a few moments, if the eyes are suddenly turned to a white surface, a colored after-image of the colored object is seen upon the white background. Usually the after-image is approximately complementary to the original color. These phenomena of contrast play a large part in nearly all color effects and should be studied and taken into account in color-schemes.

As indicated by the existence of after-images, color sensations do not decay instantly on the cessation of the stimulus. It has been found that they do not rise instantly to full value and that there is an "overshooting" beyond the final value of the sensation. Furthermore, the rates of growth and decay differ for the various color sensations.

A phenomenon which is sometimes of importance is that known as the Purkinje effect. At low intensities of illumination the retina is relatively more sensitive to radiant energy of the shorter wave-lengths, such as violet, blue, and green, than at high intensities. For example, if two colors such as blue

and orange appear of equal brightness at high intensities of illumination, the blue will appear considerably brighter than the orange when the intensity is reduced to a low value.

Different zones of the retina vary in their sensitivity to colors, depending, however, upon many factors such as brightness and size of the retinal images of the colored objects. The peripheral retina is practically insensitive to color but it is sensitive to brightness. The minimum perceptible brightness-difference is about the same for all colors at high illumination but varies considerably for different colors at low intensities of illumination.

Visual acuity is better in monochromatic light than in light of extended spectral character; however, this advantage has not found wide practical application. It is the opinion of many, based upon general experience but not on quantitative experimental data, that the eye is less fatigued under an illuminant containing energy of all wave-lengths. The mercury arc emits light approaching monochromatism more closely than other common illuminants and minute details at the threshold of discrimination are seen more distinctly under this illuminant than under others; however, this advantage, which arises from the chromatic aberration of the eye, decreases in magnitude for ordinary vision because the eye is not ordinarily engaged in the perception of minute details bordering upon the limit of discrimination. These are a few facts which are pertinent in lighting especially, when it is considered to be as broad in scope as visual activities. These phenomena and many others will be found treated elsewhere in greater detail.

Relatively little is known regarding the physiological and psychological effects of color upon the human organism. Some of these effects have been investigated but much work remains to be done. Conclusions along these lines at present must depend largely upon experience and the knowledge unearthed in many fields. Regarding such effects and the esthetics of color, few data of a definite character based upon scientific research are available but there is some degree of definiteness attainable by combining with these, the knowledge gained by experience.

One of the most vulnerable points of attacking the psychology of color is that of color-preference. Several scientists have investigated this aspect of color and when all influences and associations are excluded as completely as possible and the colors are chosen for "color's sake" alone, it appears that pure colors are decidedly more preferred than tints and shades. Furthermore, there is a decided preference in general, in the case of pure colors, for those having hues near the ends of the spectrum, namely, blue and red. There is some evidence that the color most preferred by men is blue and by women is red although the results are not sufficiently conclusive and the influences are too manifold to warrant a final decision. It is strange that, when the preference is investigated on the basis of "color's sake," the least-preferred colors lie near the middle of the spectrum; that is, near the yellow, because this is quite contrary to the preference exhibited in the choice of colors in decoration. The colors most generally used about us for permanent decoration are tints and shades possessing hues predominantly near the yellow of the spectrum but on the foregoing basis these are in general the least preferred. Though such information may have its value in lighting and certainly does have its place in the applications of color, it must be used with caution. The contradiction noted in the foregoing may be explained by assuming that the momentary delight in viewing the colors more rarely used in large proportion for permanent decoration, sways the judgment in favor of them when associations are eliminated as completely as possible. The fact that we do not accept these colors in large proportions to live with permanently indicates that the time-element is a factor.

Investigations in various publications of the use of colors in advertising, indicates that red is used very much more than any other color with the exception, of course, of white and black. Experiments on the attention-value of colors indicates that characters printed in red attract the attention much more than those in black when both are viewed simultaneously. By exposing different colors to view on a white ground for a very brief period such colors as red, black, green, and orange appear to be noticed more generally than other colors. Of

course, there are many factors which must be considered and the application of the meager results available must be made with caution; however, the results obtained in the study of various aspects of the psychology of color seem to correlate fairly well.

There is a general agreement in classifying colors into warm, neutral, and cold groups. These attributes seem to be applicable to the colors of the spectrum in a definite manner. The cold colors are those near the blue end of the spectrum; the neutral are found near the middle in the neighborhood of green; and the warm colors are in the region of yellow, orange, and red. Neutrality appears to be approached again near the extreme ends of the spectrum and in mixtures of these, namely, the purples.

The attributes which are bestowed upon colors arise from various causes and a color may be agreeable under a given environment or attitude of mind and quite unpleasant under other conditions. The judgment may be based upon the appearance of the color as to brightness, saturation, etc.; upon the physiological effect such as stimulating, soothing, heating, etc.; upon association such as mentally applying it to some portion of wearing apparel; and upon the "character" or expression of the color. The last is the most complex and represents the highest cultivation in the appreciation of color. Those who have cultivated this type of appreciation of color are the least of all influenced by associations. Their appreciation of color is essentially emotional and may be said to be esthetic in the highest sense. There is no doubt as to the growth of our liking or disliking for certain colors.

The following are a few attributes which have been applied to some of the principal colors and which under many conditions appear to be appropriate.

Red—warm, exciting, passionate.
Orange—warm, exciting, suffocating, glowing, lively.
Yellow—warm, exciting, joyous, gay, merry.
Yellow-green—cheerful.
Green—neutral, tranquil, peaceful, soothing.
Blue-green—sober, sedate.

Blue—cold, grave, tranquil, serene.
Violet—solemn, melancholy, neutral, depressing.
Purple—neutral, solemn, stately, pompous, impressive.

Though it is difficult and perhaps unwise to stamp the various colors with the attributes which they seem to possess owing to the influences of many factors, it is certain that the study of color as it has appealed to many types of individuals of all degrees of civilization reveals an expression or language of color which is more or less definite. There are many sources of such information, such as mythology, primitive language, ecclesiasticism, poetry, painting, and nature, and there are some accepted general principles pertaining to the harmony and esthetics of color. From a study of the employment of color in these various fields one is convinced of the potentiality of color.

Perhaps the attributes of coldness, warmth, and neutrality of colors are more generally noticed and are used more designedly in decoration and furnishings than any others. A room with northern exposure may be relieved of its coldness by a proper choice of color. The skylight which enters the windows may be changed to a yellowish hue by filtering through shades or hangings of warm tints and the surroundings will appear more cheerful. The general color-scheme in wall-coverings and furnishings often should be one which leans toward the warm colors for rooms of northern exposure. However, in many cases, especially in hot climes, the colder colors may be used in rooms of southern exposure and even in those of northern exposure. In rooms of northern exposure, daylight openings may be glazed with glass possessing a tint of warm yellow. Such glass is rare but it is to be found in the market at times. Weak tints of amber or canary are readily obtainable in glass but these are usually far from satisfactory owing to their greenish tinge and conspicuousness as colors. A warm yellow tint will be practically unnoticed where a lemon yellow of equal saturation and brightness will appear conspicuously colored when these are associated with illuminants.

In artificial lighting the color of the luminous portions of the lighting unit is likely to influence the impression far more

than the actual color of the light which illuminates the surroundings. For example, if a direct-indirect luminous bowl is a deep yellow in color most persons will unconsciously associate this color with the useful light even if most of the latter arrives indirectly at the point of interest practically unaltered by reflections from neutral walls and ceiling. The resultant light is a mixture of the unaltered indirect component and the comparatively small direct compound of deep yellow light. In order to illustrate this point more fully, let us take the reverse case where the bowl is a white opal glass and the ceilings and walls are decorated a moderately saturated yellow. Now the resultant light may be of the same color as in the previous case, but it is a mixture of a yellow indirect component due to selective reflection from the surroundings and an unaltered direct component. However, many persons would proclaim the lighting to be garish white or cold, because in the impression made upon them, the color of the lighting unit, if it is in a conspicuous position, is a prominent factor. It is interesting to note the part that illusion plays in lighting; in fact, it is easy to conclude that in illusions some of the greatest possibilities in lighting are found.

The psychological effects of the surroundings are very important in many aspects of lighting and may be taken advantage of in solving some problems. Some excellent examples may be drawn from experiences with artificial daylight and ordinary artificial light, for the former is white and relatively cold as compared with the yellowish artificial light. Through the persistence of habit, nurtured by experience, it is natural to expect an artificial illuminant, especially at night, to be of a warm tint. This has led some to express their displeasure with the psychological effect of the cold artificial daylight despite its superior rendition of colors; however, the surroundings may be utilized effectively in swaying the impression. Let us take the show-window where the portion of the scene occupied by the goods on display is a small part of the total scene. Artificial daylight from concealed units will illuminate the goods satisfactorily though the coldness of the scene may be effectively reduced or neutralized by having the backgrounds decorated

or draped in warm colors. Where the artificial-daylight units are used at night it is inadvisable to have the surroundings in cold colors. Another example is that of illuminating paintings on a wall. An illuminant of daylight quality is nearly always highly desirable for such purposes but there has been an objection due to its apparent coldness at night. It is gratifying to note that museums are abandoning this prejudice and that proper lighting is becoming a primary consideration. If warm gray surroundings are provided for the paintings, the coldness of the setting largely disappears. The gilded frame is also a factor in adding warmth to the setting.

The foregoing illustrates that decoration is intimately interwoven with lighting in the broader sense. If we are to employ light to the limit of its possibilities in lighting effects, the texture and the distribution of brightness and color of the surroundings must be considered. The mood or impression of an interior may be modified by varying the distribution and color of the light even if the decorations remain fixed; however, this is a handicap in lighting which could be removed by considering lighting and decoration jointly. At this point the harmony and esthetics of color enter the lighting problem very prominently but it is beyond the scope of this volume to discuss these intimately. They are touched upon occasionally in other chapters but in closing it is well to note that there are two broad classes of color-harmonies; namely, those of sequence in hue, and those of contrast. In "painting with light" the former, which approaches the monochrome, has its value but perhaps a note of light contrasting in color with the color of the more general light, is a most pleasurable simple expedient because the beauty of the delicate tints of the dominant light are brought to life by this vital spark.

CHAPTER X

SIMULATING THE SPECTRUM OF DAYLIGHT

An artificial illuminant of the spectral character of daylight is desired for several reasons. Owing to the comparative uniformity in the amounts of energy distributed throughout the visible spectrum of daylight, this illuminant is the most generally acceptable for the illumination of colored objects. Most of the artificial illuminants are poverty-stricken in the blue end of the spectrum and some of them are still less suitable for the illumination of colored objects owing to gaps in their spectra. The foregoing might be advanced as a scientific reason for the superiority of daylight for the purpose in mind but a more practical reason is that color-technology has developed under daylight and mankind has learned to base its judgment of colors upon their daylight appearances. Owing to the different appearance of colors under ordinary artificial light, uncertainty and confusion arise in the judgment of colors and accurate color-work is generally impossible. Under modern conditions many activities are pursued after nightfall. In those cases where colored objects are exhibited and color-work is done—and they represent a larger class than commonly supposed—an illuminant of daylight quality is much to be desired.

Besides these reasons there are faults to be found with natural daylight on the basis of momentary fluctuations in intensity and in spectral character. Furthermore, it changes in quality from season to season owing to the change in the selective reflection of natural outdoor surroundings such as vegetation. In crowded cities, daylight is altered considerably by reflection from painted buildings, brick walls, etc., so that, owing to all these influences daylight is far from being constant. Outdoors there are two fairly constant qualities of daylight on a clear day, namely, north skylight and noon sunlight. Owing to the shifting clouds and their variations in density these qualities of

daylight are rarely constant for any period. Even at an elevation high above the earth and buildings, the effect of selective reflection from the surface of the earth is noticeable for the chlorophyl bands, characteristic of the light reflected by green vegetation, have been detected in the integral daylight, although these are absent in the daylight at sea as has been found by measurement. In consideration of all of these influences it is evident that, for very accurate color-work, an artificial daylight is desirable even in the daytime because such an illuminant has the advantage of being constant in intensity, distribution, and quality. Incidentally the distribution of light is not unimportant in its influence on the appearance of colors.

In simulating the spectrum of daylight it is necessary to decide which quality of daylight should be reproduced. Noon sunlight is more nearly white than skylight although it has not been standardized as white. North skylight has been much favored for color-work but from various discussions with expert colorists in various fields it is concluded that its choice has been due largely because it is the most constant of all the daylights. If clear sunlight were depended upon there would be many disappointments because for many days in succession the sun is obscured and it cannot be depended upon even throughout a given day. Measurements show that the variations in the intensity of north skylight (on this hemisphere) are very much less than that of the skylight from any other direction. When the sky is overcast the resultant light is a mixture of blue skylight and direct sunlight. Sometimes the resultant light on an overcast day is quite purplish in hue but the variations in the quality of north skylight are not sufficient to be extremely troublesome.

There appear to be fields for both artificial noon sunlight and artificial north skylight of the spectral characters shown in Fig. 7. The former is to meet the demand for white light of a practicable luminous efficiency for general lighting and the other to provide an illuminant which more nearly approaches the daylight usually encountered indoors and which is a close match to the kind of daylight more generally in use by colorists. There are three possible methods of obtaining artificial day-

light, namely: (1) directly from an artificial light-source; (2) by combining two or more illuminants; and (3) by altering an illuminant in spectral character by the use of selective or colored filters.

The Moore carbon-dioxide tube emits a line and banded spectrum which approaches closely to a spectral character between that of sunlight and blue skylight. It may be said to simulate very closely the combined light from the sun and blue sky or the light on a thinly overcast day. This illuminant is in use for accurate color-work.

The "snow-white" flame arc emits a spectrum filled with closely crowded lines which, it is claimed, approximates the spectrum of combined sunlight and skylight. One of the requirements of accurate color-work is steady illumination but the flicker of the arc may be largely overcome by the use of two or more arcs operating simultaneously.

Some of the new gas mantles are said to approach daylight in spectral character but no analytical data are available to the author.

A few years ago a mercury-vapor arc was combined with a tungsten lamp, which was termed an orthochromatic lamp, the tungsten lamp supplying the red rays which are practically absent in the light from the mercury arc. This combination gave a subjective white light which was an improvement over either illuminant alone but which could not be used for general color-work of an accurate nature owing to the excessive energy of a few wave-lengths representing the mercury spectrum.

For cases of emergency, and perhaps for special purposes, colored lamps of a hue complementary to a commercial illuminant may be combined with the latter to make white light. A number of instances are on record where blue-green tungsten lamps were combined with clear tungsten lamps to provide a white light for the illumination of colored objects. This may be done very easily for a temporary purpose by the use of colored lacquers properly mixed to obtain the blue-green complementary to the yellowish light from the tungsten lamp. A considerable correction of tungsten light can be made toward daylight by coloring the inner surface of a reflector possessing

a rough surface such as exhibited by aluminized surfaces. The reflected light is altered to a blue-green color by selective reflection and this light when added to the unaltered cone of direct light results in an integral light which is materially corrected toward daylight. An impractical feature from the viewpoint of obtaining a standard quality of light is that the amount of correction depends upon the portion of the light flux which is intercepted. For this reason various reflectors would give different results.

The most extensive applications of artificial daylight have been through the use of specially developed glasses, greenish-blue in color, which have been used both for bulbs of tungsten-filament lamps and for accessories in the form of plates and blown glassware. The advent of the gas-filled tungsten lamps made this method of producing artificial daylight practicable on a large scale although the scheme has also been applied to gas-mantle units with success. Artificial noon sunlight is produced with gas-filled tungsten lamps operating at about 16 lumens per watt with a loss of about 50 per cent. in luminous efficiency, and artificial north skylight at a loss of about 80 or 85 per cent. in luminous output. However, luminous efficiency is scarcely considered in the case of the artificial skylight units because of the necessity for them. Before such units were available a great deal was said regarding the luminous efficiency but it is found that this point is seldom mentioned by those whose output or convenience is concerned. It is impracticable, if not impossible, to produce a colored-glass filter which alters an illuminant to an exact reproduction of a specific daylight quality so that the final proof of acceptability is found in actual practice. For this reason spectral analyses are of little value in comparisons but must form the basis for the development of such filters. The chief point to note is that, for example, an illuminant may appear white but unless examined spectrally none but an expert may be able without considerable experimenting to judge whether or not it approaches sufficiently close in quality to that of the daylight which it is supposed to simulate.

The noon sunlight units find applications in the rougher classes of color-work such as lithographing, commercial art,

etc., and may vary further from the ideal than the skylight units because the discrimination of color is not very exacting. There is a vast field of commercial, industrial, and office lighting where cost must be considered and for this reason another daylight unit has appeared. It represents a compromise between quality and cost of light and is a gas-filled tungsten lamp equipped with a blue-green bulb, being known commercially as the Mazda C-2 lamp. The light from this lamp approaches sunlight in quality and its luminous efficiency is about 65 per cent. of the same lamp equipped with a clear bulb. The color of the light is a warm daylight and is especially adaptable to many lighting problems. The quality of the light approaches that which would result if the tungsten filament of a clear lamp could be operated at a temperature hundreds of degrees above its present melting point.

The developments along this line have been chiefly to imitate daylight and thus the question of *white* light has not entered. The problem has been to meet the demands of practice rather than to reproduce in quality an ideal regarding which there is no agreement. There have been offered on the market a number of so-called "daylight" units which have had little merit but these have not withstood the test of practice. The eye alone cannot always be accepted as a judge of the approximation to daylight which has been attained but notwithstanding the necessity for spectral analyses of these illuminants the final product is a compromise between the contemplated ideal and practical considerations.

A few years ago before the commercial exploitation of many artificial-daylight units there was much speculation as to the requirements but the final tests are those of actual practice. We are now able to draw conclusions from many installations of various types of units and these are presented in the next chapter.

CHAPTER XI

APPLICATIONS OF ARTIFICIAL DAYLIGHT

Artificial daylight is now available from various types of lighting units and as a commercial illuminant it is a rapidly growing factor in lighting practice. A few years ago when discussions of artificial daylight were centered about theoretical and impracticable units, the supposed field for such units was usually limited to stores and to textile industries. Since the development and commercial exploitation of units more generally adaptable, the field has enlarged far beyond the limits set by those experienced in the illumination requirements of various activities. Owing to this expansion and to the continued recession of the horizon of artificial daylight it appears of interest to discuss many of these applications briefly. In considering future applications of artificial daylight it is well to note that even when natural daylight is available it cannot be brought into interiors without cost. The construction of the daylight entrances is more expensive than ordinary roofing and blank walls. In crowded cities the space sacrificed for light-courts and windows reduces the possible income from a given area of ground. Furthermore, the increased cost of heating buildings containing large areas of glass is not an inappreciable item. With the decreasing cost of artificial light it is conceivable that the future may witness a keener competition between artificial and natural lighting.

For the sake of brevity in expression, all units will be presented under two classes, namely, skylight and sunlight units. The Moore tube is in use in some fields for accurate color-matching. This emits an excellent quality of light for this work. The "snow-white" flame arc has found some application for accurately discriminating colors and gas-mantle units provided with colored filters are in use to some extent. Illuminating glassware of proper spectral characteristics is available for use

with various units, chiefly the gas and incandescent filament lamps. Besides these there are available at present, gas-filled tungsten lamps equipped with blue-green bulbs which have been more generally installed than other units. This lamp, known commercially as the Mazda C-2 lamp, emits a light of a quality approximating sunlight, and owing to its relatively high efficiency and adaptibility it has been extensively applied.

Many factors such as luminous efficiency, cost of lighting, natural prejudices, and the degree of approximation to natural daylight, have influenced the development and adoption of artificial-daylight lamps and accessories. For accurate color-work most of these factors vanish and the skylight units are chosen. For this field there are available the Moore tube, the "snow-white" flame arc, and gas and electric units employing an accurately correcting filter. But even in this field difficulties arise because the colorist has been accustomed to a specific daylight quality peculiar to his location. It is impracticable to provide artificial daylight of many different qualities to suit the vagaries of daylight (and of colorists) but if an artificial daylight has been developed properly it is fair to submit it as a substitute for natural daylight not only on the basis of its spectral character but on account of its constancy in distribution, intensity, and quality. Fortunately the need for such units is so urgent that petty prejudices are easily swept aside.

But there is a great field for artificial sunlight units where the esthetic taste is a prominent factor. Habit has decreed that an artificial illuminant for many places should be yellowish instead of white. In such cases all the skill of the lighting specialist in employing the psychological effects of the environment is necessary in order to provide the quality of light needed without offending the esthetic sense. The sunlight units are more adaptable to these cases besides providing a satisfactory quality of light. Perhaps the greatest difficulty encountered lies in convincing the consumer that he should take the long step from the warm artificial light to the cold artificial daylight. In this connection it is well to avoid installing a few artificial-daylight units for general lighting in the midst of a number of ordinary yellowish units because not only will the quality of the

light suffer by admixture with the uncorrected light but the daylight units will appear bluish by contrast with the units which contain the yellowish illuminants. Installations should be completely changed over in order to avoid the effects of contrast. The apparent coldness of artificial daylight in stores is not often noticed by the customer if the light is quite well diffused throughout the store for the impression which the lighting makes upon a person who is unfamiliar with the installation is that the store is exceptionally well-illuminated by means of natural daylight. This is an important fact which has been brought out in many cases.

The chief points can be discussed best by means of actual cases so an attempt has been made to record some of the more important fields which artificial daylight units have already invaded.

Stores.—Among these are included tailor shops, dry goods, clothing, millinery, and furniture stores as well as many others. In most of these cases skylight units are desirable at the counters or in special locations for accurate color-matching. These save the time required by both the clerk and the customer to walk to a window or doorway which is commonly done. Throughout the store general-lighting with sunlight units is satisfactory. Perhaps the most annoying condition in stores is the conflict of yellow artificial light coming predominantly from units overhead with the bluish skylight arriving nearly horizontally from distant windows. The ceiling should be fairly neutral in color in order to avoid the alteration of the indirect component by selective reflection especially where this component is relatively large as in the cases of indirect and direct-indirect lighting.

Little objection to the coldness of the artificial daylight is encountered in stores which are well supplied with natural daylight because the artificial and natural daylights blend so well but where this objection is encountered, the lighting specialist has recourse to suggestions regarding the decorative scheme. This objection rarely comes from the customer. Touches of gilt or warm shades on the columns, and sparingly on the walls and ceiling, work wonders in relieving this impression. Inci-

dentally it is convenient and desirable to have two small connecting rooms lighted respectively by ordinary artificial light and artificial daylight where the customers may discriminate the colors under either illuminant. This applies particularly to the sale of gowns, rugs, furniture, millinery, etc., which require daylight illumination for proper inspection.

Show-windows.—Artificial-sunlight tungsten lamps have been installed quite extensively in show-windows. There appears to be no better place for them for the functions of a window are to attract attention and to display goods. The problem is relatively simple because the units ordinarily should be concealed. The light is directed upon the goods and the warmth of the setting may be retained by warm tones in the background and draperies. Not only are textile goods displayed well under artificial daylight but many other commodities. In some localities, automobile display rooms have been equipped largely with sunlight units. The deep shades of color commonly employed for painting automobiles are often undetectable under ordinary artificial light.

Art Galleries.—No interiors have a stronger claim for the necessity of light of a daylight quality. The great value of works of art should arise from their appearance and in justice to the artist (and to the public) his product should be exhibited under light approximating daylight in spectral character. The sunlight units are more satisfactory for lighting works of art and a number of galleries have been lighted by artificial daylight.

Microscopy.—The importance of the quality of light in microscopy is well known. Observations which are continued after nightfall are made usually with more certainty under artificial daylight. The natural colors of minute objects are not only important but the technology of staining is equally dependent upon the discrimination of color. Both types of units are in use in microscopy depending usually upon the individual requirements.

Cigar Factories.—Cigars are sorted in respect to color and the varieties of shades of brown are distinguished with difficulty if at all under yellowish artificial light. Both the skylight and

the sunlight units are in use and there appears to be little difference in the results obtained with these units in the discrimination of the various browns displayed by tobacco.

Color Factories.—Skylight units are in use for more accurate color-discrimination and color-matching and sunlight units are employed for general illumination of processes less exacting in the requirements of color-perception. The products of such factories when exhibited in stores or used in paint shops are also at present illuminated in many cases by means of daylight units.

Paint Shops.—Skylight units for accurate color-mixing and for the standardization of colors are employed in considerable numbers but in general in this field the sunlight units are used. The final product is well-displayed under such illumination and as a consequence many automobile display rooms, for example, are illuminated by the sunlight units.

Textile Mills.—In dye-mixing and testing, skylight units are in use. Rows of such units are also used parallel to the perches upon which the dyed materials are hung. An angle unit is found necessary in some cases in order to illuminate the material which hangs vertically and is inspected by the light transmitted as well as by that which is reflected by the material. In accurate dyeing even the most experienced colorist who is thoroughly familiar with the spectral characteristics of his dyes is often unable to be sure of his ground without an illuminant of daylight quality. The sunlight units or those emitting light approximating sunlight in quality have found many applications in various textile mills. The same difficulties in discriminating the colors of textiles persist in the wholesale and retail stores, so that many of these establishments have been equipped with various types of artificial daylight units.

Garment Factories.—Both types of artificial daylight have been applied to those industries, including woolen mills and cotton mills.

Cotton Exchanges.—Although the discrimination of different qualities of cotton is included in the foregoing classification this activity deserves special mention. Raw cotton is sorted into a vast variety of grades in which color is an important

factor. The colors vary from a white to a yellowish-white, and the tints are so weak in hue that it is quite impossible to discriminate many of them from each other under ordinary yellowish artificial light. The skylight units are employed for this work.

Furs.—All the difficulties of the discrimination of color are met in the fur industries. Not only do the lighter tints present difficulties under ordinary artificial light but also the dark shades which are so commonly encountered in furs. Both classes of artificial-daylight units not only are in use in the industrial activities but have been installed by wholesale and retail furriers.

Color-printing.—In mixing inks and in inspecting proof, skylight units are employed and for the presses the sunlight units find wide application. An interesting feature of artificial daylight in color-printing, besides the satisfactory rendition of the blues, violets, and purples, is the resulting contrast of yellows upon white backgrounds under this quality of light. Under ordinary artificial light it is difficult to distinguish the yellow impression on white paper in three-color printing. Pressmen find difficulty in distinguishing flaws under such conditions which sometimes results in considerable spoilage. In lithography, art work on the original drawing and the work on stones is now being favorably done under artificial-daylight illuminants. Wall-paper displays are well illuminated by the sunlight units, hence the latter have found their way into wholesale and retail wall-paper stores.

Art Studios.—Installations of artificial daylight have been made in studios of pure and applied art. Oddly enough, artificial daylight of a sunlight quality is often preferred notwithstanding the general choice of natural north-skylight for such studios. This seeming contradiction is likely to lead one astray if further inquiry is not made. North exposure has been chosen in general by artists not chiefly for the sake of the quality or color of the light but because north-skylight is the most constant natural daylight both in intensity and quality or spectral composition. Some discerning artists prefer to paint from models in the warmer light in order to have their

paintings tend toward the warmer tone. For example, a model appears warmer in general tone under a warmer light and, therefore, the artist will paint in a warmer tone. In fact, one of our greatest artists proposed to illuminate the model with artificial sunlight and his canvas with artificial skylight in order to insure the warmth of tone which he desired. Incidentally the output of art studios is materially reduced during winter which is usually a busy season. It is significant to note the acceptance of artificial daylight by artists.

Metal Work.—The discrimination of the various colors of such alloys as brass and commercial gold is very difficult under ordinary yellowish artificial light because the various mixtures appear nearly if not exactly the same in color. Under artificial daylight the differences in the various yellows of the foregoing examples are readily distinguishable from each other. Difficulties arise with other metals and alloys in which color-discrimination is of considerable importance. The sunlight units are usually satisfactory in these cases. Lacquering activities are often more satisfactorily prosecuted under light of daylight quality.

Ore Refineries.—Color plays an important part in the selection and judgment of ores and of ore concentrates and as a consequence this field has been invaded by artificial-daylight units. A bluish-gray ore appears gray under yellowish artificial light and a yellowish ore cannot be distinguished easily if at all from another specimen of a gray or yellowish tint. In the former case, the specimen is found to be a bluish-gray under artificial daylight and in the latter case the yellows are easily distinguished. A case encountered in practice is the presence of yellowish pyrites in lead or zinc concentrates.

Chemical Analyses.—In such work color-discrimination is often of importance. The requirements vary so that either the skylight or sunlight units are satisfactory depending upon the case. In titrating, the skylight units appear to be more satisfactory. The concentration of a weak solution is sometimes estimated by the color of a considerable depth of the solution. An example of this is the yellowish color of chlorine solutions. When of low concentration this yellowish tint can

be distinguished with difficulty if at all under ordinary artificial light.

Laundries.—Dirt, spots due to scorching, and other blemishes which are generally yellowish in hue are more readily distinguishable under artificial daylight than under ordinary artificial light. "Bluing," which is used to neutralize the yellowish hue of white fabrics, can be applied with more certainty under artificial daylight. The sunlight units are usually satisfactory in laundries.

Paper Mills.—In the manufacture of paper the problems of distinguishing delicate tints of approximately white papers and of tinting pulp to match certain standards are commonly met. Artificial daylight has met these problems satisfactorily.

Flour Mills.—In a similar manner artificial daylight units are in use for distinguishing the delicate tints of flour.

Sugar Refineries.—Skylight units are in use for distinguishing the colors of sugars.

Jewels.—Color is an important factor in the value of jewels and the illuminant influences the colors of jewels quite markedly. Diamonds present special difficulties because commercial diamonds vary in color from blue-white to a decidedly yellowish tint. The former lose their bluish tinge and the latter appear less yellow under ordinary artificial light. The skylight illuminants are usually desired for purposes of examination of jewels. Pearls and opals often lose some of their beauty under ordinary artificial light owing to the suppression of the blues and violets and to the shifting of the pinks toward red.

Dentistry.—Matching artificial teeth, cements, porcelain inlays, etc., present difficulties both in factories and in the dental offices. Skylight units are in use for the more exacting work but the sunlight units are found quite satisfactory for much of the work.

Woodwork.—Under yellowish artificial light it is difficult to distinguish the colors of various woods and the variety of tints of the same wood because these are ordinarily of a yellowish or reddish hue. In furniture manufacture it is often necessary to match wood with care and it has been found that artificial sunlight is a desirable illuminant for such work.

Medicine and Surgery.—Artificial daylight has found its way into hospitals and private offices for use in surgical operations and in diagnosis. Various types of units are in use depending upon the requirements and upon the desires of the users. It is difficult to distinguish the various colors of healthy and diseased tissues and manifestations of skin diseases are sometimes unrevealed or difficult to observe under yellowish artificial light.

The foregoing are a few of the activities in which artificial daylight is in use. These are sufficient to bring forth the ramifications of the problem of discriminating color in industrial and commercial activities; however, there are many more applications on record. The following are some of the additional places and activities in which artificial daylight is in use at the present time: barber shops, hairdressing, haberdasheries, button factories, green houses, shoe stores, libraries, undertaking, chiropody, dry-cleaning, displays of colored photographs and of ordinary photographic negatives, breweries and upholstering.

Many unique and unexpected applications have been met in practice and it appears that the field for such lighting units will be greatly extended. Instances have been found in which users have declared that a light of a daylight quality is easier on the eyes for close work than yellowish light. In the absence of a decisive method of testing this point such statements must be given some attention, especially inasmuch as it is a reasonable possibility when viewed from the standpoint of evolution and adaptation. One of the most prominent features is the miscibility of artificial daylight with natural daylight. There appears to be an unsatisfactory condition of lighting when natural daylight must be reinforced with yellowish artificial light. As a result of this many installations of artificial daylight have been made in offices, drafting rooms, etc., where the discrimination of the colors of objects is of little or no importance. In many of these applications esthetic taste is a secondary consideration. Where this is a primary factor the resourceful lighting specialist may be able to solve the problem satisfactorily. There are many ways of using artificial daylight which satisfy the esthetic sense.

CHAPTER XII

SPECIAL APPLICATIONS OF COLORED LIGHT

There are many special uses for illuminants of certain spectral compositions some of which will be described not only for themselves but to give the reader a broader view of the importance of the spectral character of the illuminant. Through intimate acquaintance with the spectral characteristics of illuminants and of filters and with the lighting requirements of many activities, the lighting specialist may greatly extend his usefulness beyond the boundaries more generally recognized.

In the field of photography the lighting specialist has a number of avenues open to him whereby he may be of service. Artificial lighting in the portrait, commercial, and moving-picture photographic studios is becoming an important factor owing to its constancy, adaptability, and general reliability. The most common illuminants in use for making photographic negatives are the mercury arcs, the various carbon arcs, and the gas-filled tungsten lamps among which the special blue-bulb (Mazda C-3) photographic lamp is the most practicable. The problem of distributing the light in the most efficient manner is clearly one for which the illuminating engineer is especially trained and the problem of obtaining the proper lighting effects is one for the lighting artist. Observation in this field has led to the conclusion that the specialist in lighting can do much in coördinating science and art in photographic studios. The problem is chiefly one of devising easy controls for obtaining a flood of light and dominant light of various degrees of directedness. Combinations of these two extremes provide a vast variety of artistic effects.

There are many factors involved in the choice of photographic illuminants which are so interrelated and differently evaluated depending upon the conditions or effect which is desired, that

it is impossible to establish a common basis for comparison. Actinic or photographic value is the first requirement and in most cases adaptability or ease of control of the distribution of light is doubtless the factor next in importance. In the latter, the portability of the lighting units is often of importance. Investigation has shown that generally the cost of energy is much less significant than the two factors mentioned above owing to the relatively small portion of time in which the lighting units are in operation in the photographic studio. Furthermore, it is obvious that the economics of the problem must not be based upon the facts of ordinary lighting but upon the facts of "photographic" lighting.

In the photographic dark-room several colored illuminants are necessary depending upon the photographic emulsions involved. It is well known that most ordinary emulsions are sensitive chiefly to ultra-violet, violet, blue, and blue-green rays and practically insensitive to yellow, orange, and red rays. For this reason red light is quite commonly used for the illumination of dark-rooms for the purpose of manipulating ordinary plates. The red should preferably be without an orange hue and should appear a very deep red. This may be obtained by the use of red glass or red lacquers although it is not uncommon to find that the latter often transmit violet light appreciably. By adding a yellow lacquer this fault may be remedied. For handling printing paper which is much less sensitive as a rule than ordinary plates and films, an orange-red or even yellow light is quite satisfactory.

Panchromatic emulsions are sensitive to all the rays of the visible spectrum and also to ultra-violet rays. However, the sensitivity of such emulsions is by no means the same for energy of all wave-lengths and a relatively low sensitivity is often found in the green region between 0.5μ and 0.55μ. This is near the spectral region of maximum luminosity of radiation at low intensities; therefore a low intensity of illumination from a fairly monochromatic illuminant having a maximum of luminosity near 0.50 to 0.52μ (green light) is found satisfactory for handling panchromatic emulsions. It would be quite out of place to discuss the illumination requirements of photog-

raphy in detail but a few have been touched upon in order to bring this field to the attention of the lighting specialist. There are many other requirements met by various illuminants; for example, the arcs are in use for blueprinting and photo-engraving and many tungsten lamps of all sizes are in use for printing. Gas lamps are in use to some extent in photographic studios.

In signalling, the ranges and visibilities of colored lights are important factors. It has been found that for a given illuminant the range increases approximately directly with the candle-power when the absorption of the atmosphere is negligible. To what extent the color of the illuminant affects the range or visibility of a signal light is not accurately determined but it is found to be quite an influence under practical conditions of atmospheric absorption. It has been shown that fine particles of water-vapor, dust, smoke, ice and perhaps the molecules of air scatter the violet and blue rays more than the other visible rays. For this reason an illuminant in which yellow, orange, and red rays predominate should penetrate farther under ordinary atmospheric conditions than one rich in energy of the shorter wave-lengths. This is especially noticeable by the reddish color of the setting sun which indicates that the energy of short wave-lengths in the visible spectrum have suffered greater absorption or scattering than the longer wave-lengths. The scattered light should therefore be of a bluish color similar to skylight which apparently is scattered sunlight. This fact has led to the development of search-light and automobile headlamps equipped with yellow screens. It is not only claimed that by eliminating the violet and blue rays there is less scattering in dust and fog but that there is less glare from the yellow light. The latter point is quite in doubt at present but there appears to be a possibility of a slight advantage in yellow screens from the viewpoint of the observer behind the lamp owing to the reduction of the "veiling" glare due to the scattered light; however, this point requires more definite proof.

One of the most important factors which influence the choice of colored illuminants for signalling purposes is the brightness or intensity obtainable under practical conditions. It is well known that ordinary illuminants contain relatively small

amounts of violet and blue rays and for this reason, purple and blue are essentially short-range signals. Yellow is the most luminous but red is more striking and practically unmistakable. Fortunately it possesses the desirable characteristics of fair luminosity, relatively slight alteration in intensity and in color by atmospheric absorption, and striking appearance. Blue-green is usually of fair luminosity and green and orange are other possible signal colors. Signal lenses have other practical uses in lighting especially as screens for obtaining fairly pure colored illuminants.

It is obvious that a danger signal may possibly come to be ignored if it burns steadily at all times; therefore it appears that a haphazard flicker in intensity from a certain moderately low value to a high one would be desirable. At no time should the brightness become zero or even so low as to be unnoticeable but certainly there would be some value in a superposed, spasmodic flicker for attracting attention.

Some time ago it was brought to the author's attention that a battleship which had just been launched was equipped with a lighting circuit of blue lights for use when in an engagement at night or at least when near the enemy. The reason for using the blue lights was not clear but doubtless was for the purpose of obtaining maximum luminosity with sources of low intensity. It is a physiological fact of vision that at low intensities the wave-length of maximum visibility is in the blue-green region of the spectrum in the neighborhood of 0.51μ. This is a fact that might well be borne in mind in selecting phosphorescent materials for special purposes.

It has become well established that visual acuity or the ability to discriminate fine detail is better under monochromatic light than under an illuminant of extended spectral character. This fact may be taken advantage of in special cases. Monochromatic light is satisfactorily used for microscopy and should have other applications. Among the common illuminants the mercury arc approaches monochromatism more closely than any other. Most of the luminosity is due to the green line (0.546μ) and the twin yellow lines (0.577μ and 0.579μ). The maximum visibility of radiation of ordinary intensities lies

close to the green mercury line at about 0.55μ. This is a fact to be noted in special cases where a purely monochromatic light of high intensity is desired. The green mercury line may be isolated by suitable screens and perhaps is the best monochromatic illuminant available for visual purposes. It is known that the eye ordinarily focuses blue objects with difficulty except at close range so that such factors usually must be considered.

The author has made experiments on the effect on visual acuity of absorbing from a continuous-spectrum illuminant the rays near the ends of the spectrum. For example, by the use of yellow filters, varying in saturation, more and more of the blue end of the spectrum of tungsten light was absorbed, the resulting light varying in seven steps from the unaltered yellowish tungsten light to a deep amber. Although the experiments were not thoroughly conclusive it appeared that visual acuity remained practically constant notwithstanding the reduction in the illumination due to the yellow filters. It appears that there are possibilities of such applications to special problems in future lighting.

Light is in use for medicinal purposes but little is known along this line except the germicidal action of light, especially of ultraviolet rays. The psychologist and physiologist must unearth more data before the lighting specialist can do much more in this field than to carry out the wishes of others. However, there are many cases in which the lighting specialist may be helpful by analyzing the spectra of illuminants and filters and by providing colored illuminants as well as by properly equipping ordinary illuminants for medicinal purposes.

The problem of simulating the color of older illuminants such as the candle flame is a scientific one, the chief aim of such a realization is to satisfy the requirements of esthetic taste. There is no doubt that the warm yellowish tint of the light from the candle flame, kerosene flame, and carbon-filament lamp is very pleasing in many interiors; however, the haphazard attempts to imitate such illuminants by means of colored filters applied to modern light-sources fall far short of success. The usual procedure has been to take a yellow coloring element

and incorporate it in glass, lacquer, or other medium but this invariably has resulted in an amber color. If the esthetic sense is so finely tuned as to require the unsaturated yellow illuminants it is certain that in general the greenish-yellow, characteristic of light tints of yellow coloring media, will not be acceptable. Amber illuminants border on the spectacular whereas the inconspicuous yellowish tint of the candle flame is an artistic color which blends harmoniously in many interiors. The best proof of the foregoing is to illuminate two diffusing glass bowls with amber and "candle-flame" illuminants respectively. The former will be conspicuous to everyone whereas the latter will not appear "colorful" though the "warmth" of the light is felt. It may be said that the latter color is felt but not seen.

Silk fabrics are more readily obtainable of the proper color than other colored media. Ordinary yellow glasses or lacquers lose their greenish tinge by the addition of a pink and the desired yellow may be thus obtained. By mixing the light transmitted by a very deep yellow-orange glass with clear tungsten light a fair result may be obtained. This may be done as in Fig. 11. The author has obtained the color in glass with a single coloring element under proper conditions and also in lacquers and in other superficial coatings. Such developments are certainties of the future in order to convert modern illuminants into those warmer tints so satisfactory for many interiors.

It may be of interest to learn the highest efficiencies at which illuminants of the spectral characters of the candle flame may be obtained by applying filters to the tungsten lamps operating at various efficiencies. These are presented in the accompanying table with similar values of efficiency for simulating the spectrum of the carbon-filament lamp (3.1 m.p.c.) Obviously light of the quality of that emitted by the carbon lamp can be obtained at a higher luminous efficiency from the tungsten lamp equipped with a proper filter than from the carbon lamp itself. These values were computed and represent accurate spectral matches. Under the less rigid requirements of practice somewhat higher luminous efficiencies of the filtered light may be expected. In the first column the normal operating efficiencies is given for clear lamps.

SIMULATING OLD ILLUMINANTS BY FILTERING TUNGSTEN FILAMENT LIGHT

Lumens per watt		
Tungsten-filament lamps	Filtered to simulate	
	Candle flame	Carbon filament
(Vacuum type)		
6.0	3.9	5.3
8.0	4.5	6.3
10.0	5.0	7.1
12.0	5.6	8.0
14.0	6.0	8.9
(Gas-filled)		
8.0	5.1	7.4
10.0	5.7	8.4
12.0	6.3	9.3
14.0	6.9	10.2
16.0	7.4	11.0
18.0	8.0	11.6
20.0	8.5	12.2
22.0	9.0	12.7

Colored glasses have been used for modifying daylight before it enters interiors. A yellowish tint somewhat similar to that required for converting tungsten light to a color approximating that of the candle flame alters blue skylight to the color of sunlight. A glass of such a color should find many applications in buildings and it is not beyond the bounds of possibility to find such glass come into use for glazing north windows in office buildings. The north skylight is cheerless and when we begin to realize the psychological effect of the color of light, the finer points of lighting will be given closer attention. Incidentally there appears to be a need for skylight glass which is fairly opaque to infra-red rays. Such glass would rob sunlight of some of its energy and therefore aid in keeping interiors cool.

The possibilities of utilizing light of various colors or qualities are numerous and represent a definite line of development in lighting. The foregoing discussion treats a few of these not only for themselves but for the purpose of suggesting the scope of this relatively untrodden field.

CHAPTER XIII

SIMPLE PRINCIPLES OF LIGHT-CONTROL

With the practical development of the possibilities of controlling the distribution and quality of light, the lighting specialist finds many interesting fields outside those of ordinary interior and exterior illumination. The development and the installation of such devices as projection lanterns, searchlights, headlights and lenses as well as ordinary lighting equipment are often left to him. It is not uncommon to be confronted with the problems involving both the quality and the distribution of light for photography and even for medicinal and various hygienic purposes. As the lighting specialist becomes qualified he finds that he is called upon to supply illuminants for dye and paint testing, for bleaching purposes, and at least to render opinions in many other fields. There are many applications of colored light especially in relation to chemical and physiological phenomena. It is quite beyond the scope of this volume to discuss this aspect widely but a glimpse of various phases and specific applications will be presented.

Control of the distribution of light is obtained by reflection and by refraction. There are many kinds of surfaces available for lighting purposes which are used to control light by reflection but among the transparent or translucent substances, glass is the most commonly used. However, glass is a name which applies to a large variety of compounds or mixtures varying considerably in their optical characteristics. Perhaps no better idea of the control of light or of the appearance of object due to the light reflected and refracted by them can be obtaine than by a few simple illustrations.

In *a*, Fig. 12, *I* represents an incident beam of light upon a mirrored or optically plane surface, and *R* the reflected beam. It is a simple law of optics that the angle of incidence is equal to the angle of reflection for a beam of light incident upon an

optically plane surface. In practice, the so-called mirrors such as polished metals and other materials, chemically deposited metals, varnished surfaces, and various glazes reflect light regularly as indicated in *a*, Fig. 12. It is evident that excellent control of light is possible by the use of mirrored surfaces of contours.

There are many surfaces which diffuse the incident light almost perfectly as indicated by *b*, Fig. 12. It is seen that the beam incident upon the diffusely reflecting surface is scattered in all directions. "Flat" paints, blotting paper, dry pigments and plaster as well as many other surfaces are diffusely reflecting but perhaps no surface is perfectly so.

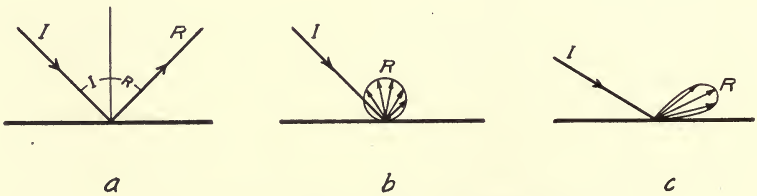


FIG. 12.—Common reflection characteristics.

Another type of reflection is illustrated in *c*, Fig. 12. This "spread" reflection is exhibited by sand-blasted and aluminized surfaces, depolished brass, and others. It will be noted that the light is maximally reflected at an angle of reflection corresponding to the angle of incidence although the reflected beam is somewhat scattered. If the beam of light is incident perpendicularly to the surface the latter will reflect relatively more light perpendicularly if it has a reflecting characteristic like that shown in *c*, Fig. 12, than if it is perfectly diffusing as shown in *b*, Fig. 12. Although this fact is of chief interest in lighting from the viewpoint of the design of reflectors, it is exceedingly pertinent to the moving-picture screen. In theatres whose width is small compared with the length, a screen of the spread-reflection type has advantages but in comparatively wide theatres a diffusely reflecting screen is necessary in order that the pictures will be bright enough when viewed by those seated near the sides of the room or at con-

siderable distances from the center-line connecting the projection lantern and the screen.

The maximum reflection-factors of such surfaces as indicated in Fig. 12 are not greatly different in value. Under excellent conditions 0.9 is about the highest value maintainable in practice for either the regularly reflecting mirror or the diffusely reflecting white surface. Many combinations of these characteristics are encountered in practice; for example, a white enamel surface or a sheet of blotting paper covered with thin glass gives a combination of the types illustrated in *a* and *b*, Fig. 12.

With translucent or transparent substances, the phenomenon of refraction is present. This may be best illustrated by a

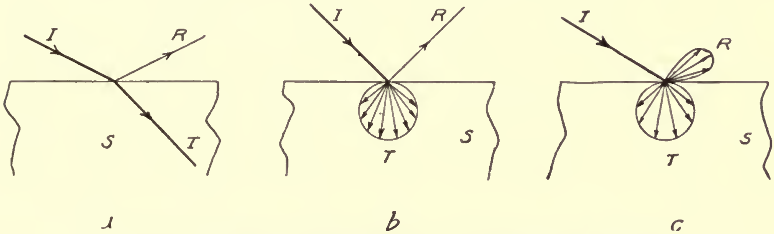


FIG. 13.—Common characteristics of transmitting media.

few cases. In *a*, Fig. 13, a beam of light *I* is shown incident upon a transparent surface of *S*. A portion of the light, *R*, is shown reflected regularly from the polished or glazed surface but the remaining portion *T* is transmitted though in another direction. The fact that the direction of *T* is different than *I* indicates that the refractive index of *S* is different than that of the medium through which *I* passes. For a given angle of incidence the portion of the incident light which is reflected by the surface depends upon the refractive indices of the two media. If *S* is ordinary glass surrounded by air, the portion of the reflected light is about 4 per cent. for each surface if the beam of light is incident perpendicularly to the surface. This proportion increases with the angle of incidence, slowly at first then more rapidly and obviously no light enters *S* when the incident angle becomes equal to 90 degrees. The relation between the reflection-factor for an ordinary thin sheet of

clear glass and the angle of incidence is shown in Fig. 14. The lower curve is for the first surface with the beam of light incident from air and the upper curve is for the two surfaces. The index of refraction of the glass is 1.52. The transmission-factors may be determined in any case by subtracting the reflection-factor from unity, assuming no absorption in the glass.

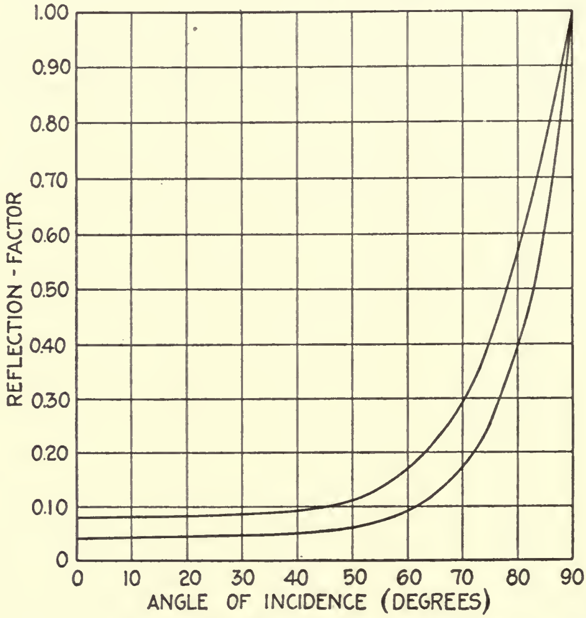


FIG. 14.—Relation of reflection-factor and angle of incidence of light on a thin polished plate of glass having a refractive index of 1.52. Upper curve for two surfaces; lower curve for one surface.

If the substance is highly diffusing and possesses a polished surface, the result is as indicated in *b*, Fig. 13. Some of the light which is diffusely scattered in the medium *S* finds its way back into the air but this is not shown in the diagram. If the surface is sand-blasted, *c* represents the optical characteristic. In practice, two polished surfaces are often encountered close together as in the case of thin clear glass. The most important reflected and transmitted rays are shown in the full lines in Fig. 15. A portion of the incident light would be accounted for in R_1, somewhat less in R_2 and practically the remainder in the transmitted beam T which has been refracted

at each surface. If the two surfaces are parallel T proceeds in the same general direction as I but slightly displaced. As a matter of fact if a certain portion of the total incident light is reflected at each "air-glass" or "glass-air" surface, it is obvious that there are many other reflected and transmitted beams as indicated by the dotted lines. These become negligible because they contain but a small portion of the original incident light. If the second surface of the thin glass is silvered the intensity of R_2 will be high. This accounts for the double reflected image seen in plate glass and mirrored glass.

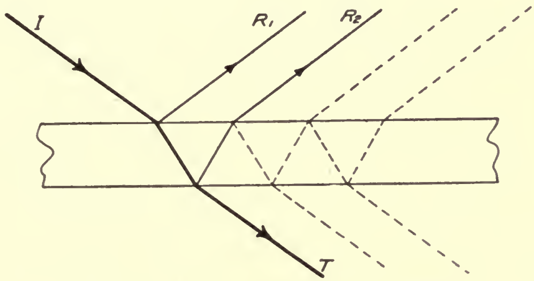
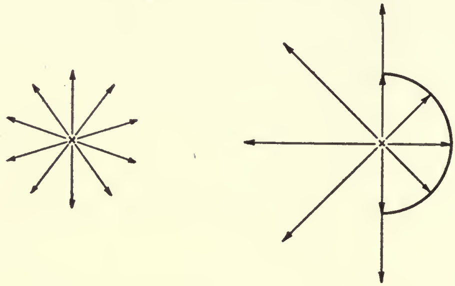


FIG. 15.—A thin plate of polished glass.

Reflection is a factor in all reflectors whether opaque, transparent or translucent. It appears unnecessary to illustrate how ordinary lighting units of different types of distribution are obtained because this field is one for the specialist in designing. His tools are optical laws, characteristics of the surfaces and media at his disposal, and the distribution curves of light-sources. However, it should be of interest to illustrate a few of the applications of optical principles in the control of light which are useful to the lighting specialist in solving certain problems. Many of these are based on the assumption of a point source of light which is never realized in practice. For this reason certain compromises are made in design and often certain difficulties arise which cannot be readily overcome.

The focus of a spherical mirror is at the center of curvature; that is, at the center of the spherical envelope. If a point source which emits light of equal intensities in all directions, *a*, Fig. 16, be placed at the center of curvature of a spherical

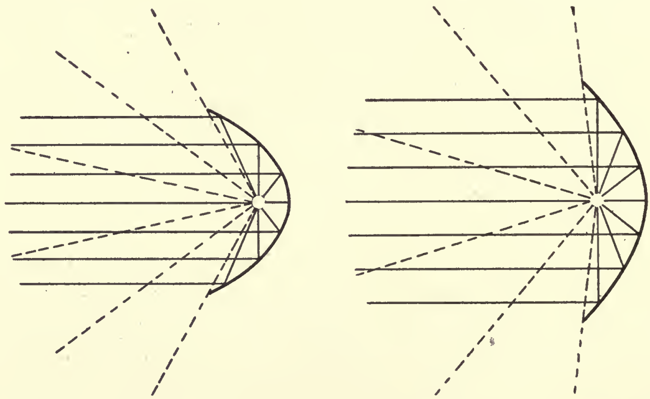
mirror of 180 degrees solid-angle as shown in *b*, Fig. 16, the intensity in the various directions away from the mirror will be increased. If the silvered spherical surface is perfectly



a *b*

FIG. 16.—The spherical mirror.

reflecting the intensity in any direction away from the mirror is doubled. This condition is not realized in practice but the spherical mirror may be used to advantage to approach such



a *b*

FIG. 17.—The parabolic mirror.

a result. If the spherical surface is diffusely reflecting, the maximum intensity will lie on the axis but the distribution of the light from the unit will differ very much from that shown in *b*. Furthermore, the output will be less than in the case

of the mirrored surface even with the same reflection-factors of the mirrored and diffusing surfaces owing to the greater absorption due to internal multiple reflections (and therefore absorptions) in the case of the diffusing surface.

The law of the parabolic mirror has been utilized in such units as searchlights, headlamps, and flood-lighting units. If a point source be placed at the focus of such a mirror, the rays intercepted by the reflector are rendered parallel as indicated by the full lines in *a*, Fig. 17. There is always a cone of direct light emitted as indicated by the dotted lines. Although there are many practical considerations which limit the design it is evident that the larger the solid-angle of intercepted light, the greater is the percentage of the total light which is rendered

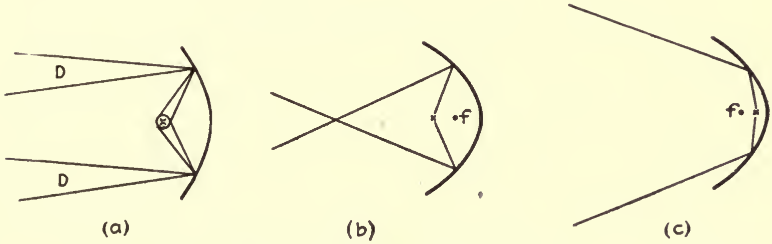


FIG. 18.—The parabolic mirror.

parallel. The shallow parabolic mirror shown in *b* emits a greater percentage of unintercepted light in the direct cone than the relatively deeper unit shown in *a*. If the direct cone of light is not desired, it may be eliminated or at least reduced in importance, by means of circular black diaphragms placed in front of the unit and perpendicular to the axis or by opaque cylinders concentric with the axis. Such simple expedients are useful in special problems. Inasmuch as light-sources are not confined to the theoretical point there is a certain spread or lack of perfect control in nearly all commercial units. The automobile headlamp is especially important and it is interesting to note why the parallelism is not obtained. This is shown in *a*, Fig. 18, where the light-source is shown as a small sphere. Small cones *D* replace the theoretical straight lines in the preceding illustrations. If the light-source is in front

of the focus the rays cross in front of the reflector as shown in *b*. By placing a semicircular shield over the lamp or aperture to cut off the rays emitted by the lower half, the remaining light is seen to be directed below the horizontal. If the light-source is behind the focus the rays diverge as shown in *c*. In order to eliminate the upward light it is necessary to obstruct the

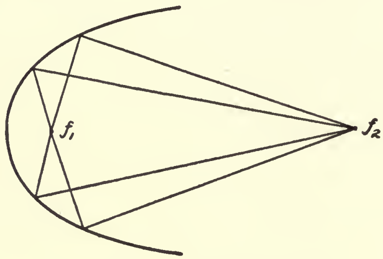


FIG. 19.—The elliptical mirror.

light emitted by the upper half of the unit. These are simple expedients which have been applied more or less successfully to automobile headlamps.

The principle of the elliptical mirror is that if a point source of light is placed at one focus f_1, Fig. 19, the light-rays will be

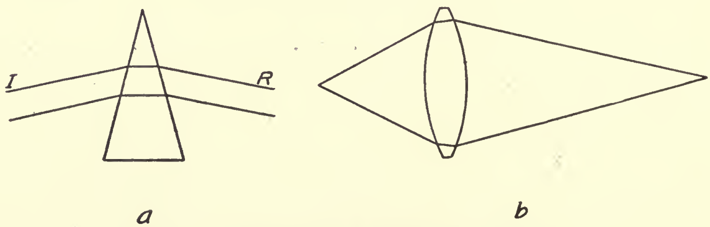


FIG. 20.—Refraction of a prism (*a*); of a lens (*b*).

brought to a point again at the other focus f_2. These illustrate some of the principal simple laws of reflection.

Some of the possibilities of controlling light by refraction will be illustrated by simple examples. If a beam of light *I* in *a*, Fig. 20, be incident upon a prism of glass it will be bent from its source and will emerge in the direction of *R*. Under the conditions of a small parallel beam the emergent ray will be spread out into a spectrum owing to the fact that the refractive

index of the glass varies with the wave length of light. This has been treated in another chapter and inasmuch as the condition is seldom met in practice, no account of prismatic dispersion will be taken in the present discussion.

A simple lens may be considered to be described by a prism rotated about its base. Thus in *b*, Fig. 20, the focusing effect of a simple lens is illustrated. Rays of all wave-lengths do not come to a focus at the same point for the same reason that they are not all deviated by the same amount by a prism. This is a fault of all simple lenses which is known as chromatic aberration. It is corrected by combining with a simple convex lens a glass of another refractive index. For information on combinations of lenses the reader should consult a book on optics.

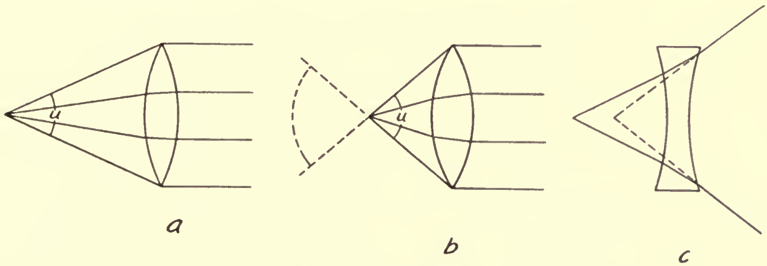


FIG. 21.—Lenses.

If in the case of a simple convex lens, the light-source is placed at a distance equal to the focal length of the lens the rays of light are rendered parallel on emerging as shown in *a*, Fig. 21. With lenses of short focal length, *b*, the cone of light, *u*, which is utilized is greater than with lenses of longer focal length, *a*. A spherical silver mirror placed behind the source in *b* in such a position that its center of curvature is coincident with the light-source, will increase the luminous output of the lens in the case of some commercial sources. The position of the mirror and the cone of light reflected by it are shown by the dotted lines in *b*. The divergent beam from a concave lens is shown in *c*. The rays of light appear to come from a source close to the lens as indicated by the intersection of the dotted lines. Total reflection from glass surfaces is often utilized in the control

of light, for example as shown in Fig. 22, where *I* and *R* are respectively the incident and reflected beams. Light-rays are totally reflected from a "glass-air" surface when the angle of incidence is as great or greater than the angle shown provided they are passing through the glass medium just before reaching the surface which is bounded by air.

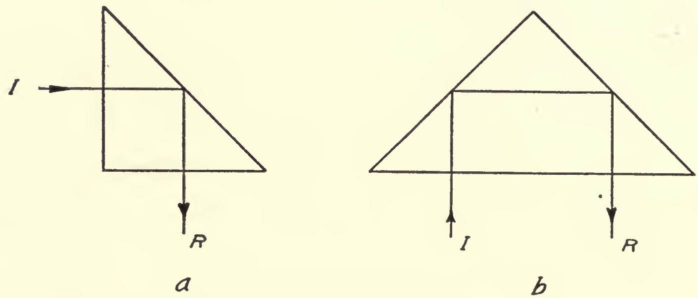


FIG. 22.—Total reflection in glass.

Prism glass is used in many ways in illuminating engineering. There is a vast variety of designs most of which employ the principle of bending the ray through an appreciable angle by refraction as illustrated in Fig. 23. In employing prism glass

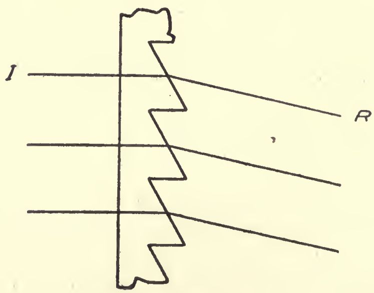


FIG. 23.—Prism glass.

there are many points to be considered, especially the character of the light-source; that is, whether it be of small solid-angle or of large solid-angle such as an expanse of sky. In lighthouse lenses and other signal lenses the principle of refraction is successfully employed in controlling light-rays and prismatic illuminating glassware has been used extensively for many years.

In summarizing it may be stated that the principles involved in controlling the distribution of light are chiefly those of reflection and refraction. Those surfaces or translucent media which scatter the light have comparatively narrow limitations

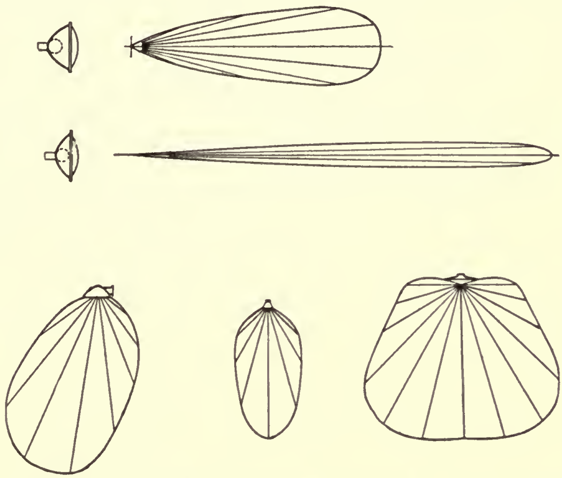


FIG. 24.—Control of light by devices possessing mirrored surfaces.

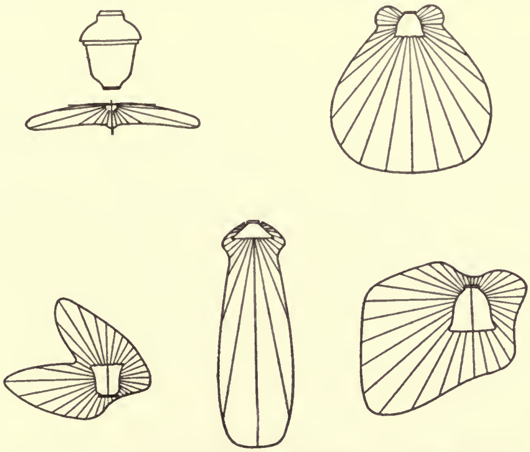


FIG. 25.—Control of light by prismatic glass devices.

as controlling media although they serve the requirements of a vast amount of lighting in an excellent manner. This class is represented by aluminized and enamelled surfaces and by sand-blasted, etched, and opal glasses. Polished metals and

silvered glasses are only limited in their ability to control light by such practical considerations as the accuracy with which the surfaces can be made to approach the ideal and the concentration and brightness-uniformity of light-sources. The diversity in the control obtainable by mirrored surfaces is represented in Fig. 24 as well as in some of the preceding illustrations.

Similar remarks apply to the utilization of reflection and refraction of glass. In Fig. 25 are shown a few of the different distributions of light obtainable by applying these principles in the design of so-called prismatic glassware. Even greater concentrations may be obtained by means of prismatic lenses and combinations of simple lenses such as are employed in optical instruments. These principles are the tools of the designer of lighting devices and are available to the lighting specialist in solving his problems.

No doubt there are many special combinations of the principles of reflection and refraction which will be adapted to the light-sources and to requirements of the future. In this chapter merely a brief glimpse of a few simple principles has been given, however, these few principles form the basis of light-control.

CHAPTER XIV

LIGHTING AND ARCHITECTURE

The relation between lighting and architecture is of interest from several important viewpoints. During the design of a building a general idea of the lighting plan should be determined so that the necessary provisions may be made during the construction. If the lighting plans are not fairly well-defined at this time, it is not uncommon for the lighting specialist to be confronted with obstacles which could have been avoided. Owing to this lack of consideration of the lighting early in the design of a building, much criticism has been heaped upon architects for their lack of coöperation with lighting specialists. This criticism is just in many cases but there is another viewpoint which must be considered in justice to the architect, namely the attitude of the lighting specialist toward his problems. In the case of a beautiful architectural work the architect maintains in his imagination the final picture or effect which he is striving to realize. In this final result, lighting is only one of the factors—but it is an extremely important one. If the architect consults a lighting specialist and finds that the latter attacks the problem as if it were purely an engineering one it is not surprising that the architect is disappointed. If the lighting specialist does not appreciate that the architect is striving for an effect and is not designing a building for the purpose merely of housing a lighting system which is to provide an illumination of a certain number of foot-candles upon a given plane, he cannot render much service which the architect cannot obtain from his own staff. The spacing and locating of outlets in accordance with the decorative patterns is a simple procedure quite obvious to many outside the lighting field. The lighting specialist should be able to suggest the placing of outlets, the types of units, the influence of the decorative scheme, the effect of light in modelling ornament, and the

general psychological and artistic effects of certain distributions of light, shade and color upon different details, areas, and the interior as a whole. A few lighting specialists are capable of doing this but there is much progress to be made by the rank and file who practice illuminating engineering.

However, the architect often reveals his own lack of appreciation of the importance and potentiality of lighting by postponing the consideration of lighting until the building is well under way. He has solved many of the problems of daylighting because these must be considered even in the first sketches but the possibilities of artificial lighting have enormously extended in recent years so that he has not yet fully appreciated their full value and importance. Thus it is seen that both the architect and the lighting specialist are responsible for the much discussed lack of coöperation between them. A thorough treatment of the subject of this chapter would extend into a large part of lighting practice so that only a general introduction will be presented. The relation between lighting and architecture crops out in other chapters and has been treated in an analytical manner elsewhere.[1] There are certain fields, such as industrial and office lighting in which the purely utilitarian and hygienic aspects are of chief or of sole importance. In such cases the illuminating engineer is doing excellent work and the architect may find plenty of expert assistance among these engineers in solving the natural and artificial lighting problems. The procedure in such cases is largely that of illuminating engineering, the practice is fairly well standardized, and helpful data are available. However, in those cases where the decorative and psychological aspects of lighting predominate, the practice is not standardized and perhaps never can be. Individuality is a characteristic in these cases and a procedure must be adopted which aims to produce the effect desired. The first step is to obtain a definite idea of the architect's goal and therefore a thorough discussion of the construction, ornamental details, decorative scheme and other factors must be obtained by consultation and from specifications.

First, let us consider the effect of the distribution of light

[1] M. Luckiesh: "Light and Shade and Their Applications," 1916.

upon architectural details and upon the artistic and psychological aspects of an interior as a whole. It should be recognized that lighting models objects and makes areas distinguishable from each other. These light and shade effects aided by the colors of details and by the tints and shades of the larger areas are responsible for whatever artistic or psychological value an interior may possess. But the architect may say that this is not true, because lines, proportions, etc., contribute something. Indeed they contribute to the final effect but only through the agency of lighting.

It is interesting to speculate as to how far an impression of an interior is gained solely through that which is seen and that which is not seen but is known to be present. For example, a vertical panel in a wall may be surrounded by an ornamental molding mitered at the four corners. Only when the light is distributed upon these four pieces of molding from a point approximately upon a line perpendicular to the center of the panel will they appear closely alike. Even under these conditions they will vary somewhat in appearance at different portions. If the dominant light arrives from a source higher than the panel it is obvious that, in the general case, the upper molding will appear quite different from the lower one which presents a different side toward the light-source. Such conditions are to be found in nearly all decorative interiors yet we have little fault to find; however, if the details be studied carefully the great differences in the appearances of the same molding-design in various places are obvious. This leads to the question, How much is our impression of an interior due to that which we gain solely through vision? Certainly our ability to reason is an influence but it appears that lighting should be more carefully prosecuted with the appearances of details, areas, and the whole in mind.

A similar case will be found in the exhibition of paintings. For example, we might find a Corot badly lighted by means of yellowish artificial light and under the conditions it may not be possible to view it to advantage or to distinguish the delicate bluish grays. It is interesting to note the expressions of delight on the part of those who discover its presence though most of

the artistic value of the painting is unrevealed. Such effusions cause the searcher after knowledge to doubt the sincerity in art-appreciation of many individuals posing as appreciators. Surely the pleasure in the foregoing example is not due to that which is seen. In fine art of this character there appears to be much pleasure gained from possessing the object or from knowing that it has been caressed by the hand of antiquity or is a product of the same hand that made other objects of artistic appeal.

The foregoing is of importance in analyzing the part that lighting should play in revealing an artistic object, whether the latter be a detail or a whole interior. After considerable experimentation, observation and thought, no final answer to the foregoing question has been reached so it has appeared necessary to cling to the idea that, after all, the artistic or psychological value of an interior lies in its appearance and hence is largely a matter of lighting. The distribution of light, through the values of light and shade which it gives to the dominant areas and through its modelling of details combined with the color effects, produces the final mood or spirit of the interior. The importance of this statement is obvious to those who experiment with lighting effects and it is apparent to anyone who takes the trouble to observe lighting effects in architectural interiors such as churches and various other beautiful interiors. A striking feature of the study of lighting is that studies are to be found on every hand.

In the application of lighting to architecture many illusions will be observed. A dark alcove will appear darker as the brightness of the surroundings is increased. A bright ceiling may produce the effect of the airiness of outdoors nevertheless the ceiling is seen to be a boundary between indoors and outdoors. A dark ceiling may appear lofty and if this darkness is enhanced by means of lighted chandeliers between the eyes and the dark ceiling, the darkness may be effective in arousing various ideas or emotions depending upon the particular setting. Another fact of lighting and vision is that a bright object amid dark surroundings usually appears larger than when the light and shade is reversed. In Fig. 26 an

attempt has been made to illustrate this effect and to relate it to architecture. The dimensions are exactly the same in the two cases but the dark columns appear thinner and taller than the bright ones. Illusions should not be ignored in lighting.

Various alterations may be made in the architectural proportions of an interior by the proper application of light and shade. The decorator knows this well but for some reason lighting has not been considered as a decorative medium in the same manner as pigments. In fact, it is a decorative medium of much greater expressive possibilities than any other medium

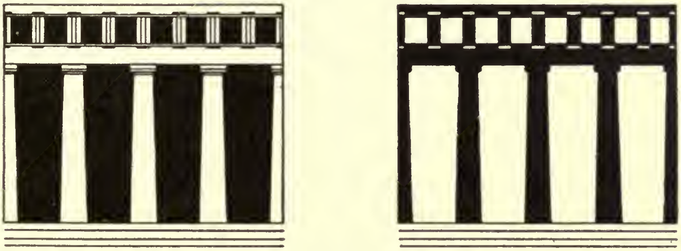


FIG. 26.—An optical illusion of light and shade.

as discussed in Chapter II. In view of this the decorative and lighting schemes should be considered together.

Fixtures may be designed and located so as to produce the best effects in modelling details and to distribute the light in a manner which is in harmony with the mood to be realized. The design may be such as to be completely in accord with the artistic scheme or period style of the interior and as such, the fixtures may be beautiful ornaments. Their locations should be considered from the standpoint of eye-comfort but the proper revealing of ornamental details is also of importance. For example, if the walls of a room are ornamented by means of very low relief, the latter will be seen better if the lighting units are placed near the walls above the relief because such details are revealed in the best manner by means of directed oblique light. Similarly, if a ceiling is covered with low relief, it is usually unsatisfactory to flood it with light from various directions. Such lighting tends to obliterate low relief. In some cases the light-sources may be concealed close to the ceiling

behind a projecting cornice and, as shown in Fig. 27, if reflectors giving an asymmetrical distribution of light are used, a satisfactory effect may be obtained. By this means the relief is lighted quite obliquely and its outlines will be apparent by lines of light and shade. Incidentally it is of interest to note that the principle of low relief approaches closely to that of drawing because usually the expression is not one of *masses* of light and shade but chiefly of *lines* of light and shade. In most other objects masses are prominent factors.

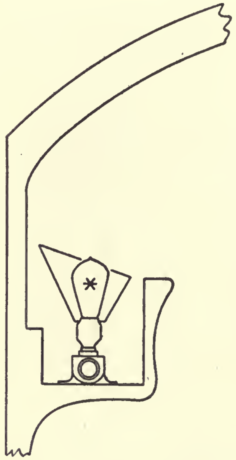


FIG. 27.—Cove-lighting.

At this point it is well to note that the appearances of objects which depend upon shadows and highlights are influenced by three factors. The position of the dominant light-source determines the direction of the shadows; the solid-angle subtended by the light-source at a shadow-producing edge determines the character or gradient of the modulation of brightness in the shadow-edge, and the scattered light and that arriving from distant light-sources determine the brightness of the shadows. These factors may be controlled to a degree in practice and thus severity or softness of effect may be obtained as well as other appearances.

The brightness of a surface depends upon its reflection-factor (hence upon the decorative scheme) and upon the flux density or illumination upon the surface. Obviously the latter depends upon the amount of light directed and scattered toward the surface, upon the orientation of the surface, upon its distance from the light-source and upon various details. The orientation of the surface is highly important and this factor should be studied in respect to ornamental patterns, large surfaces, etc. For example, the upper part of a wall—the frieze—may be brighter than the portion of the ceiling adjacent to it if it has the same reflection-factor, because the light is received by this portion of the wall more nearly perpendicularly than by the adjacent portion of the ceiling from a light-source at some dis-

tance. This is especially true in small rooms in which there is a central fixture. The reverse is often true in the case of wall-brackets.

If a light-source is suspended from the center of an architectural pattern the various surfaces of the latter will be of different brightnesses, even though of the same reflection-factor, due to their different orientations with respect to the light-source. The relation of lighting to architecture is found to involve a vast number of details such as those which have been discussed. The full import will not be grasped until much study and thought have been applied to the relation of lighting to the appearances of objects. This involves the scientific aspects of simple optical laws, the reflecting characteristics of surfaces, the distribution and color of light, and the esthetic and psychological effects of distributions of light, shade, and color.

The intensity and diffusion of daylight in architectural interiors tends to alleviate some of the difficulties which arise from lack of forethought in respect to the influence of lighting upon architecture but daylighting usually falls short of the ideal because of the difficulty in controlling its distribution. With the advantage of controlling artificial light both in distribution and in color it is far superior to natural light in the hands of a lighting specialist who recognizes the potentiality of lighting and who knows how to utilize it scientifically, artistically, and psychologically. In fact, it appears reasonable to predict that, owing to the superior advantages of artificial light in these respects, it will not be unusual to find places where artificial light is used exclusively even though daylight were available if the openings had been provided

The foregoing has touched upon some of the possibilities of lighting but no thought is entertained that the subject has been done full justice. This cannot be done without greatly extending the discussion but the aim has been to convince those interested in lighting that they wield a tool of extensive possibilities in relation to architecture. Perhaps a few examples and suggestions pertaining to the relation of construction to successful lighting may be of further interest and will help to convince the architect that he is a large factor in lighting.

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The optical characteristics of skylight glass are of great importance if artificial light is to be projected through it or diffused by it. Ornamental designs in ceilings might better be laid out in accordance with the best spacing of outlets wherever this is possible because in most cases the fixtures are supported in a manner symmetrical with the design. The distribution of light from a fixture may in some cases be adapted to the design with artistic results. Many places can be provided by the architect for concealing light-sources if such a plan of lighting appears to be most desirable. False beams, cornices, moldings, recesses in the walls, ceiling, pilasters or above capitals, or other ornamental details may be woven into the decorative scheme if these are necessary in order to provide the best lighting effect. There are cases on record where such coöperation has resulted in unique effects which are highly satisfactory. Sometimes the architect has apparently been so oblivious to the lighting requirements that he has placed a network of structural beams above and close to the subskylights, thus placing insurmountable obstacles in the way of the lighting expert.

In show-windows the architect should understand the influence of dimensions upon the lighting effect; he should supply places for concealing the lighting units; and he should understand the possibilities of lighting sufficiently to supply the proper abundance of outlets and circuits. Such details as ventilating grills are sometimes placed in positions which cause difficulties in the spacing of lighting units.

In beautiful interiors of the purer types of architecture there are perhaps still more urgent reasons for the early consideration of the lighting by the architect. After the building is completed the ingenuity of the lighting specialist may be depended upon to provide illumination but he cannot always obtain the effect which would be most desired because he is limited to a few places where outlets have been provided or where they may be installed and by other obstacles. Furthermore, it may be beyond the bounds of possibility to design a fixture which properly distributes the light and at the same time meets the requirements of period style or artistic appearance. Often it

is most desirable to eliminate visible fixtures and obviously in such cases it is necessary to provide places for concealing the lighting units. In viewing the results of lighting as related to architecture many admirable examples are found in which the indirect system of lighting from concealed sources has been utilized. Not infrequently has it been found that electric wiring is insufficient in carrying capacity although usually this may be remedied. Among the vast number of details pertaining to lighting the architect should bear in mind that the system should be readily maintainable in efficient operation. For this reason provisions should be made for easy access to the lighting units. This is often a matter of primary construction.

Besides the usual lighting requirements the architect may consider many of the more unique uses of light for special decorative effects. As an example in an interior the large basin of a fountain in the center of the room was very dark at night owing to the unusual lighting plan which was found to be suitable for the room. No provision had been made for illuminating the fountain so it was necessary to cut a hole in the ceiling about forty feet above the floor and, by means of an optical system, to project a very narrow cone of light downward just covering the basin of the fountain. This provided an excellent solution which is a testimonial of the ingenuity of the lighting specialist.

Uniformity in brightness or in illumination is often quite necessary and sometimes this is difficult to obtain over a large area such as a wall or ceiling. However, it appears that striving for uniformity is sometimes a misdirected effort. Some of the most charming effects of light and shade are due to asymmetrical distribution of light in the room as a whole. In some cases such a distribution of brightness or illumination on a wall produces very artistic effects. A case in point is that of a large mural painting which may be beautified by a proper asymmetrical distribution of illumination over its surface.

In this brief discussion of an extensive subject color has been given little consideration. The points discussed are some of those of immediate importance. The potentiality of the charm of color in lighting has been barely tapped and a great future appears to be open for this aspect of lighting.

CHAPTER XV

THE PORTABLE LIGHTING-UNIT

The portable lamp is such an important factor in lighting and the possibilities of utilizing it more widely in lighting effects are so promising that it appears of interest to discuss it independently. Two marked features of improper lighting are the prevalence of improper lighting fixtures and the usual simplicity of the remedies for converting such fixtures into satisfactory ones. Although the remedy may be simple it is seldom applied because the salesman and consumer are unacquainted with the simple laws of light. But there is another reason which is a serious one in all phases of lighting, namely, the indifference of the average person to the possibilities of lighting.

There are distinctly two viewpoints for the consideration of most portable lamps, namely, the purely utilitarian and the artistic. These are intimately interwoven but certain scientific principles may be separated and discussed. Incidentally the artistic aspect is very prominent in portable lamps because the purely utilitarian "desk-lamp" is rapidly disappearing from use with the increasing tendency toward general lighting in those places where it has been widely used in the past. However, the portable unit is becoming more popular in much interior lighting where variety in artistic lighting effects is recognized, at least feebly, as the source of much pleasure.

It is interesting to invade fixture stores as a purchaser and to study the manner in which portable lamps are discussed. This applies to nearly all fixtures with the exception of the purely utilitarian such as industrial units. The salesman discusses chiefly, and often solely, the artistic value of the portable lamp. It is true that many units are purchased for the chief purpose of supplying a source of light which serves its purpose by accidental distribution but most of these units are also intended to

supply illumination for a specific purpose such as for reading at a library table or for seeing music on a piano. Seldom does a person encounter a salesman who demonstrates the distribution of light from a portable lamp by means of a library table, a chair and a book or by holding music near a floor lamp at about the position which it will occupy under actual conditions.

A small percentage of decorative portable lamps are fit for their intended utilitarian purpose although it is gratifying to note that during the past few years a number of excellent designs have appeared. That a portable lamp may be artistic and yet utilitarian certainly cannot be questioned. However, this is not a discussion of esthetics, except indirectly, as it is usually the attempt to realize the artistic that defeats the realization of the utilitarian goal.

The utility of a portable lamp is largely a matter of dimensions of the various parts and in order to illustrate this and bring forth various points of interest a few diagrams will be used. These should serve the purpose of emphasizing to those concerned, the extreme simplicity of the principles of fixtures of this character. In order to analyze the portable lamp, the library lamp will be considered on the basis of certain definite assumptions regarding the positions of the eyes and of the book which it is assumed a person is reading. The position of the book, B, in the accompanying diagrams, is assumed to be 30 inches from the vertical axis of the lamp and at the level of the top of the table which is 30 inches above the floor. The position of the eyes, E, is taken as 12 inches above the level of the top of the table and is designated by V_E, the vertical height V of the eyes E above the plane of the top of the table. The light-source is designated by S, its height above the plane of the lower aperture of the shade by h, and above the top of the table by V_S, and the horizontal distance from the extreme edge of the aperture of the shade to the vertical axis of the unit by R. Several variables with different types of shades are considered in the following simple diagrams. The light-source is assumed to be of small dimensions but if it is not, certain obvious alterations must be made. (See Fig. 32.)

In Fig. 28 the effect of the height of the lamp pedestal is

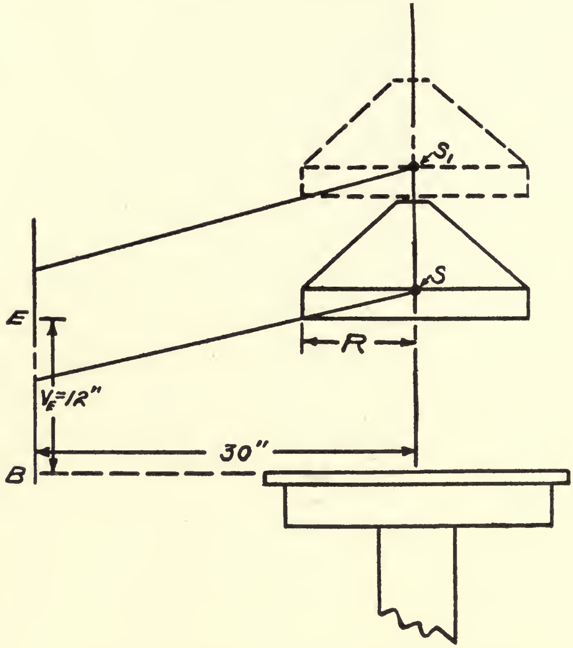

FIG. 28.—Influence of the height of a shade.

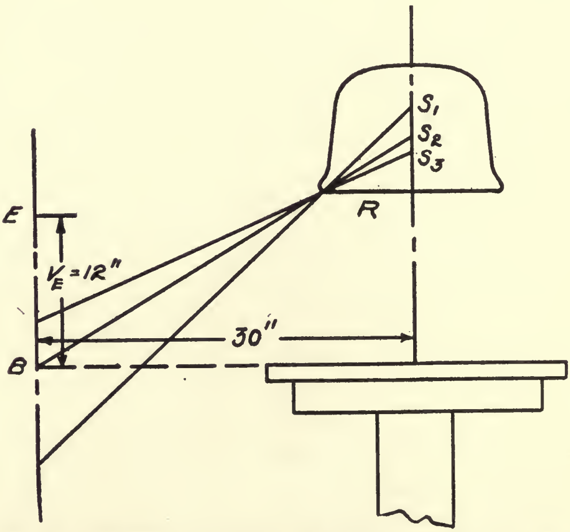

FIG. 29.—Influence of position of the light-source in a shade.

shown. The light-source is assumed to be confined to a point but for practical applications when the eyes at E are considered, the lowest point of the ordinary extended light-source is used in such a diagram and for the book, B, the highest point of the light-source is used. A primary aim should be to confine the direct rays from the light-source below the point E. It is seen that the increase in the height of the pedestal raises the limiting ray to an undesirable position. If the two limiting rays (from the highest and lowest portions of the light-source) are confined so as to cut the vertical line between E and B the lamp is satisfactory from this viewpoint. It should be noted that the book and the eyes are considered to be approximately in a plane perpendicular to this page.

In Fig. 29 is shown the effect of varying the height h of the light-source above the plane of the lower aperture of the shade. The two lower positions of the light-source S_2 and S_3 are satisfactory provided the limiting direct ray from the lower point of the source does not cross the vertical line as high as E. In such mushroom types of shades it is a common error to have the light-source too high in the shade as shown by S_1.

In Fig. 30 is illustrated the common shallow type of shade which does not confine the limiting direct ray below E. Such shades give a desirable spread of light but if the pedestal is too high it is necessary to sit so far away in order to have the limiting direct rays fall below the eye-level that the illumination is too low for comfortable reading. By shortening the pedestal in this case a satisfactory reading lamp may be obtained.

In Fig. 31 are shown the results obtained with two light-sources in the same shade. If it is desired to utilize the light from both sources, the source S_2 at the greater distance from the eye (greater effective R_2) is the important one from the standpoint of the eye and source S_1 is the important one from the standpoint of illuminating the book. In this case if both lamps are to contribute to the illumination the limiting rays of both of them must be confined between B and E for satisfactory results.

These diagrams cover the important variables in the dimen-

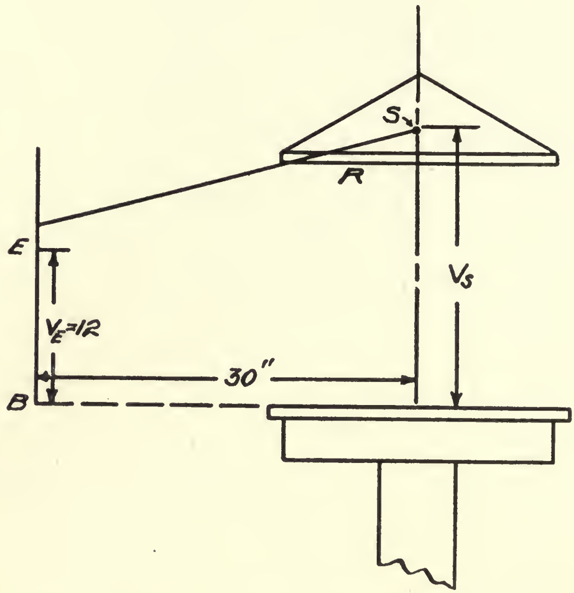

FIG. 30.—Influence of size of the aperture of a shade.

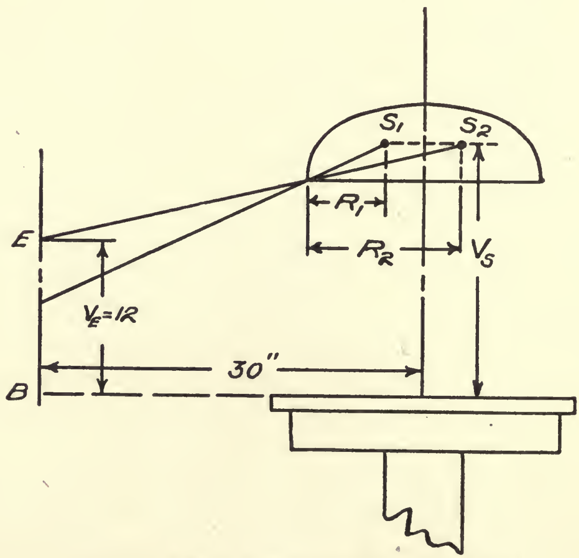

FIG. 31.—Effect of two light-sources in a shade.

sions of library lamps and though simple they will bear some study. The various relations have been brought together in Fig. 32, the dimensions being shown at the right. The relation between the ratio of R (one-half the maximum width of the aperture) to the height h of the light-source above the plane of the aperture, and the height V_S of the source above the top of the table is shown by the curve for satisfactory portable lamps

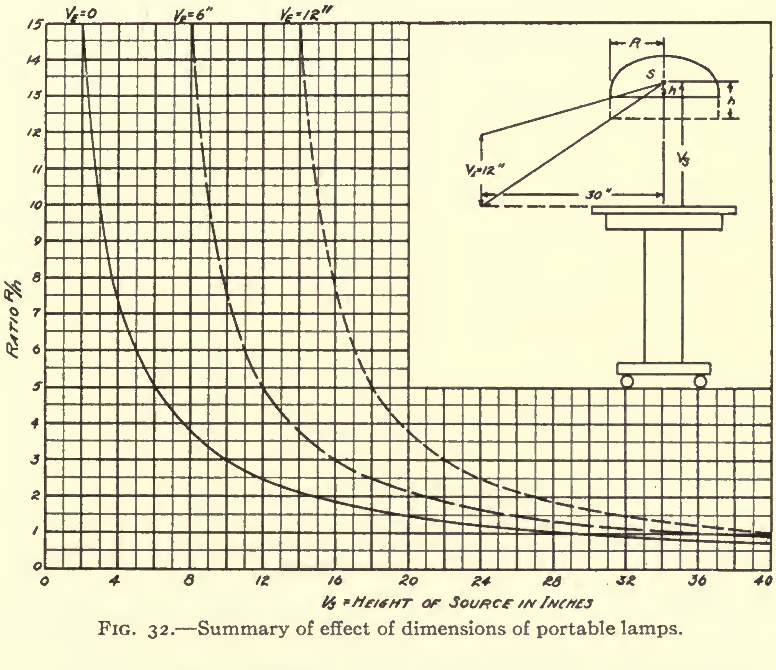

FIG. 32.—Summary of effect of dimensions of portable lamps.

for reading tables. When $V_E = 12$ inches the limiting direct ray just enters the eye at E. Another height of limiting direct ray, $V_E = 6$ inches, is considered in the middle curve. On the curve, $V_E = 0$, the condition at B is considered. From these curves it is easy to determine whether or not a library lamp of certain dimensions meets the requirements of the foregoing assumptions. It appears that for ordinary light-sources if the measurements are made to the middle vertical point of the light-source and referred to the middle curve, satisfactory results are obtained. These curves are not proposed as a guide to be used in the censorship of library lamps although they may

be used in this manner. They are presented as a brief summary of a diagrammatic discussion of the principles underlying the design of utilitarian library lamps. Many phases of lighting may be considered in a similar graphical manner with edifying results.

For the sake of simplicity the ordinary "direct" type of portable lamp has been considered in the foregoing; however, greater possibilities in lighting are found in the use of portable units from which different distributions of light may be obtained. As has already beem emphasized, portable lamps are extremely adaptable to obtaining a variety of artistic lighting effects as well as to satisfying various utilitarian requirements. If they are provided with means for obtaining at least two independent distributions of light (and a combination of the two) the flexibility of the lighting is greatly augmented. One of the greatest drawbacks in the adoption of portable lamps for general lighting purposes in the home is the common scarcity of electrical or gas outlets.

There are sufficient reasons for designing portable lamps which incorporate various scientific aspects in the control of light. Within the past few years a number of excellent designs have appeared upon the market and though portable lamps are extensively used at present, it appears that, with the development of units of greater adaptability and variety in the lighting effects obtainable, they will be much more widely used in the future not only for residential lighting but for many other fields.

In Fig. 33 a very commendable principle is shown incorporated in the portable lamp. The light-source is shielded by means of an inverted reflector *R* which may be either opaque or of dense opal glass. If the reflector is opaque the light is reflected to the inner surface of the shade *S* which is coated with a diffusing medium such as flat white paint. The effective light-source—the inner surface of the shade—is of large area and therefore may be of low brightness for a given illumination at the point of interest. This is especially desirable when the eyes are obliged to view glazed surfaces such as varnished table-tops or calendered paper for the glare from such surfaces

is very marked when the reflected images of light-sources are of high brightness. This glare is materially reduced and is often entirely absent when the effective light-source is of low brightness as in this case. The shade may be of metal into which decorative patterns have been etched or cut. In the latter case the openings may be covered on the inside with a dense translucent material. If the reflector *R* is of dense opal glass the unit is somewhat more efficient but unless the glass is

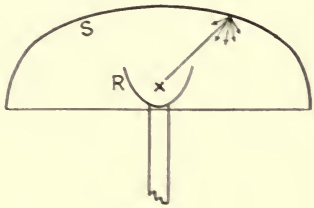

Fig. 33.

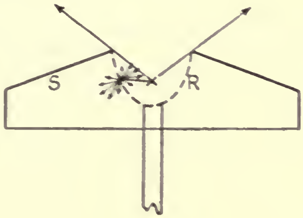

Fig. 34.

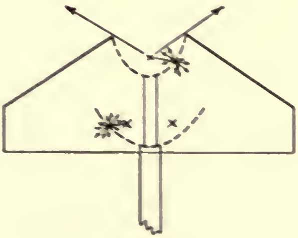

Fig. 35.

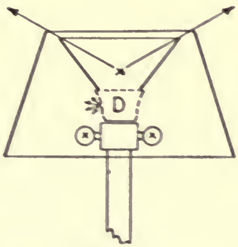

Fig. 36.

Figs. 33 to 36.—Recent progress in the design of portable lamps.

very dense it must be shielded from the eyes, for example, by means of a deeper shade, *S*, which reduces the effectiveness of the light reflected from the inner surface of the shade.

Another type of portable lamp is shown in Fig. 34 in which a diffusing glass reflector *R* is inverted. Upon this a shade *S*, usually of silk, is supported. The distribution of light from this is a combination of an indirect component with a direct component. In this lamp the inner shade may be of light-density opal glass because it is possible to shield it from the eyes

without seriously reducing the effectiveness of the unit as a reading lamp. The distribution of light is pleasing but lacks the element of variety. When the silk is of a saturated color or of a dark shade it is advantageous to provide an inner lining of white or of a highly reflecting tint.

In Fig. 35 is shown a modification of the foregoing principle which has the advantage of variety in distribution. Such a unit has appeared in a very practicable design but the principle is illustrated here in a simple manner by the use of two opal glass reflectors placed one above the other and each containing one or more light-sources. If the upper source is lighted, the resulting light is a combination of indirect and direct components. If only the lower sources are lighted the indirect component is smaller and the direct light, which consists of that transmitted by the lower reflector and reflected from the lower surface of the upper reflector and from the silk shade, is greater in magnitude. It is seen that this unit possesses a certain adaptability not possessed by the ordinary lamp.

In Fig. 36 is shown a simple but excellent type of portable lamp which may be used to illuminate a small area for reading or for decorative purposes or by means of the indirect component an entire room may be flooded with light. The upper reflector is opaque and preferably silvered inside. If a lamp of high luminous output is used in this reflector a large area may be indirectly lighted to a satisfactory intensity. Several opal or frosted lamps may be used for the direct component. A small portion of the light from the upper source is permitted to escape from the lower part of the reflector and this light is scattered in different ways thus serving to illuminate the silk shade. One of these is illustrated by the opal glass diffuser *D*. Tinted lamps or color-filters may be used for obtaining the desired colored light. By means of such a unit the distiibution and color of light may be readily adapted to suit the mood or spirit of the occasion or to meet the utilitarian requirements.

Many combinations of principles may be incorporated into portable lamps of which the foregoing illustrations represent a few possibilities. The ease with which silk and other fabrics may be utilized for shades and reflectors make it possible with

the aid of wire frames to design many unique lamps for special purposes besides providing notes of color as well as floods of tinted light obtained by transmission and by reflection. By such means those who possess an esthetic sense for color may enjoy the pleasures of "painting with light." Besides providing localized and general lighting for ordinary purposes, special reflectors may be concealed in such units, or certain panels may be omitted from the shade in order to illuminate special objects such as paintings by means of direct light from a unit. Portable lamps need not be limited to the use of the ordinary symmetrical shade, for half-shades may be used to conceal the light-source or other equipment from the eyes while from the open half, a wall, painting, book-case, or other area may be illuminated directly. Portable lamps are readily adaptable to obtaining assymetrical distribution of light as well as color which ordinarily are the requisites of artistic as well as economical lighting in many interiors. The potentiality of the portable lamp can hardly be overrated and it is to be hoped that designs for lighting in the future will make it possible to reap the pleasures from the use of such units by providing an abundance of outlets which certainly cannot be denied on the grounds of cost because the expense of such outlets is insignificant compared with their importance. Observations in average apartments, houses, and other interiors in which the portable lamp is especially adaptable lead to the conclusion that such outlets are far too rare. The architect and electrical contractor can do much to remedy this deficiency.

CHAPTER XVI

RESIDENCE LIGHTING

For several reasons the lighting of the home is among the most important aspects of lighting. It is of primary interest to the lighting specialist because it is in the home that the science and art of lighting may reach mankind in general if the opportunities are provided. Proper lighting contributes more to the attractiveness of a home than is commonly suspected and the greatest obstacle which must be removed is the indifference of mankind in general to the potentiality of lighting. This indifference will succumb only to enlightenment which must arise from the coöperative efforts of the lighting specialist, the architect, the decorator, the contractor, the fixture dealer, and the central-station representative. The central-station should have a primary interest in the satisfaction gained by the householder from proper lighting. There are many million homes in this country wired for electricity or piped for gas and the householder receives an invaluable legacy from well-directed efforts of the representative of the central-station in the cause of good lighting. The central-station may profit either through increased load or through a satisfied and interested consumer.

The architect is often a factor in the lighting results for he may be responsible not only for the outlets and the decorative scheme but also may direct the selection of the fixtures. The potentiality of lighting cannot be fully enjoyed without having a sufficient supply of outlets and there appears to be no just reason for not providing electric or gas service quite liberally during the construction of a building. The contractor is often a factor in such provisions and instead of curtailing the expenditure for a few extra outlets which may not be put into immediate use, it is not only to his advantage but also to that

of the householder to provide outlets generously. One of the chief criticisms which may be applied to residences on every hand is the scarcity of lighting outlets for without a generous supply of these essentials, the possibilities in lighting cannot be fully realized. If the householder is provided with fixtures which are so equipped and wired that variety in distribution and color of light may be obtained he will awaken to the utilitarian and artistic values of lighting. Plenty of outlets for connecting portable lamps is also a factor in overcoming the general indifference of users of light in the home.

The part that the fixture-dealer and salesman play in this propaganda for the consumer's good has already been touched upon as well as that of the decorator and the place which may be filled by the lighting specialist is quite evident. The foregoing has been introduced as a preface to this chapter because it appears to be very important. Proper lighting in the home is dependent upon those who provide outlets and fixtures and upon those who are in a position to enlighten the general public regarding the importance of good lighting in contributing to the welfare and happiness of the occupants of the home.

There are important hygienic aspects of lighting in the home but the greater possibilities lie in making the home cheerful and attractive. No modern light-source should be exposed so as to be normally visible. Such a condition is harmful to vision and contributes much toward making a home unattractive. In passing along a street at night close to residences it is not unusual to note lightings which might readily be considered to be punishments illy disguised. Although those who live in such environments may be unconscious of the ill effects of such lighting conditions, these doubtless leave their imprint upon the health and disposition of these persons. A living room may be lighted by means of an inartistic fixture containing exposed light-sources and the lighting effects may be harsh and lacking in any of the essentials of esthetics. If a reading lamp contains a bright light-source which is unshaded from the eyes, annoyance to vision, discomfort, and even ill temper may result. On the other hand, well-designed fixtures cannot produce a restful lighting unless aided by a decorative scheme which is the

result of the application of good taste and some knowledge of the interdependence of lighting and decoration.

There are few places for bare lamps in the home outside of indirect and so-called semi-indirect (direct-indirect) fixtures. Even in these units a frosted incandescent lamp or a diffusing envelope for a gas mantle reduces the harshness of the shadows on the ceiling and walls which often result from bare light-sources. In a similar manner frosted lamps in upright shades on brackets produce a more artistic effect than bare lamps. The so-called bowl-frosted lamps may often be used to better advantage in pendant shades, in showers, or in other fixtures and rarely is a bare light-source as satisfactory as a frosted or opal lamp for a reading lamp even though the light-source is shielded from the eyes. The glare due to the images of bare light-sources which are reflected from polished or varnished furniture, glazed paper, and other glossy surfaces is usually more severe than when frosted or opal lamps are employed.

Even though the fixtures are properly designed and used there may be other harmful physiological and psychological effects attributable to improper brightness-distribution. For example, the brightness of a lighting accessory, such as a glass shade, will be glaring amid dark surroundings even though it might be quite satisfactory amid medium or light surroundings. In a similar manner eye-fatigue may not be experienced on reading while facing a wall of medium brightness but under the same distribution of light extreme fatigue may result if the wall is of very low reflection-factor. While reading at a library table by means of the illumination from a well-designed portable lamp the visual field surrounding the book may be of a medium brightness and the conditions perhaps will be quite satisfactory. If the remainder of the room is in semi-darkness the psychological effect is usually conducive to concentration of attention and the semi-darkness provides a place toward which the eyes may be directed occasionally for the purpose of resting them. These and other details are of importance in the welfare of vision.

It is a difficult matter to discuss the esthetic aspects of lighting in the home because this involves individual taste

which is more or less indeterminate. However, the artistic possibilities of lighting are so extensive and important that no discussion of residence lighting can avoid the treatment of this aspect. There are certain broad esthetic principles which are acceptable and it should be of interest to discuss the artistic aspect of lighting even though the points brought forth may be defended only on the grounds of an individual taste. The variables in the lighting of the home are so numerous that all of them cannot possibly be discussed here; however, an attempt will be made to point out a few principles and possibilities.

Inefficient, unsafe, and inartistic fixtures found in residences may be discarded for the same reasons that any other unsatisfactory equipment would be dispensed with; therefore, no space need be given to a discussion of the vast number of badly designed fixtures which are in use at the present time. Furthermore, economy in lighting is of minor importance compared with the utilitarian and artistic satisfactoriness of lighting in the home. The cost of enjoying satisfactory lighting in the home need be no greater than the cost of suffering bad lighting in most cases and any reasonable outlay for the installation and maintenance of good lighting in the home is justifiable.

Inasmuch as the various rooms in a home present different lighting problems they will be briefly treated separately. Control is an important factor in lighting and, although gas may be controlled from remote switches, for convenience this aspect will be treated as though the systems were electrical. This explanation is made in order that no unjust disparagement of the possibilities of gas lighting may be construed because the progress which has been made by designers of gas-lighting accessories must always be viewed with admiration considering the difficulties which must be overcome.

Living Room.—It appears that the use of ceiling fixtures in the living room is not, in general, as conducive to artistic lighting effects as asymmetrical arrangements of fixtures. The living room should present a restful artistic appearance and in this, lighting is a large factor. A central fixture produces a symmetry in the lighting effect which lacks variety in light and shade and which becomes monotonous. If a ceiling fixture

is used it should be provided with at least two circuits so that the intensity of illumination may be controlled to some degree. As has been mentioned before, fixtures from which two or more widely different distributions of light can be obtained should be more acceptable than the ordinary fixtures. In the living-room, more than in any other room in the home, provisions should be made to adapt the lighting to the individual mood or to the spirit of the occasion. Fixtures provided with various circuits which control different distributions of light are essential if variety in lighting is to be obtained from ceiling fixtures.

If ordinary central fixtures are used the type is quite a matter of taste. If a shower is used it should be hung high, the shades should be deep and of low transmission-factor and no exposed light-source should be visible. If the so-called semi-indirect bowl is employed the glass should ordinarily be very dense opal or should be otherwise highly diffusing and of low transmission-factor. It should be hung as high as it is practicable. Purely indirect central fixtures do not appear to be as generally adaptable to living rooms as some other units although fixtures from which an indirect component can be obtained when desired are found to be convenient and desirable lighting accessories. Being largely a matter of taste, it is unwise to attempt to condemn the central fixture but attention will be directed to other means of lighting the living room which provide greater variety in effects. It appears to the author that there are certain objections which may be applied to the central fixture in many cases among these being the monotonous symmetry in the lighting effect, the prominence of the fixture and the accompanying annoyance even from the mild glare from many fairly well-designed units, and the distraction from the beauty of the room as a whole, especially if the ceilings are low. It appears to be likely that the use of ceiling fixtures in living rooms of fair size will decrease, however, in planning a residence it is a wise plan to provide wiring for ceiling outlets even though they are not to be used initially.

Brackets in which the light-sources are shaded by silk shades or by dense diffusing glass provide a means for asymmetrical lighting effects and are of decorative value. If the background

is of low reflection-factor these units must be of very low brightness in order to avoid glare. A common mistake is to place light-sources of too high luminous output in small shades. Considering the light-source to be confined to a point and surrounded by a spherical shade of diffusing glass, it is obvious that the brightness of the latter will vary inversely as the square of the diameter of the shade for a light-source of a given luminous output. Where the appearance of the unit permits their use, large shades should be used. In fact, it is surprising how large the shades may be sometimes and still be appropriate. An opal glass shade 6 inches in diameter containing a 25-watt tungsten lamp is commonly of a limiting brightness as viewed against a fairly bright wall even when the glass is of a moderate density. Brackets are conveniently controlled by means of switches attached to them with the exception of those which cannot be reached easily as might be the case with mantle brackets.

The baseboard and floor outlets are the most important in the living room from the standpoint of general adaptability of the lighting to suit the desires of the householder. Nevertheless such outlets are often the most neglected features in the plans for lighting service. In a living room of moderate size five and even ten outlets chiefly in the baseboard may be justified. Outlets on the mantle and above built-in bookcases and in various special places provide convenient connections for decorative lamps. Many places may be found for concealing light-sources such as in vases and in other ornaments. Portable lamps may be obtained in many designs; they may be equipped with silk shades or with tinted lamps; they may be placed in various positions in relation to each other or to the furnishings; and they may be controlled at will. All of these features and others conspire to make this method of lighting the living room exceedingly attractive. Variety and adaptability are represented by such a system to a higher degree of perfection than by any other scheme. A single unit with a powerful indirect component will illuminate a fairly large room and utilitarian and decorative spots of light can be obtained wherever desired. Surely no other method of lighting the living room

offers such possibilities for gleaning from lighting all of its potential value. Portable lamps are the most wieldy lighting tools for painting with light but the urgent need is for outlets to which they may be connected conveniently.

Dining Room.—The problem of lighting the dining room is more definite than that of the living room. The table is confined to a fixed position and it may be taken as the most important spot in the room. We immediately approach a psychological aspect of lighting and it appears to be the verdict of many who study lighting that the table should be the most intensely illuminated object in the room. Certainly there is a cheerfulness about a well-illuminated table hemmed in by semi-darkness. If this is the principle of lighting acceptable for the dining room, certain types of lighting do not meet the requirements. The size of the dining room and the range in the number of diners are important factors to be considered.

The so-called semi-indirect units ordinarily flood the entire room with light and the table is not the most highly illuminated spot in the room and it is seldom the brightest spot. This system does not appear to fill the requirements for the best lighting in the dining room; however, it is widely in use. Although individual taste is a large factor, it is predicted that many persons who are now using the so-called semi-indirect fixture would abandon it in favor of a modern unit which directed the dominant light to the table area if they were provided with an opportunity to compare the two lighting effects.

In large dining rooms, the use of wall-brackets may possibly be justified if candlesticks on the table provide additional illumination. However, it is difficult to provide a comfortable lighting from wall-brackets without taking extreme precautions to reduce the brightness of the unit and to have the background sufficiently bright to avoid glare. When these conditions are satisfactory the result usually is a distribution of light possessing a dominant indirect component.

In order to carry out the principle of confining the dominant light to the table area it is necessary to employ small units on the table or to suspend a fixture from a point on the ceiling above the table. If the units are placed on the table they

should be low in order not to obstruct the view of the diners and they must be well-shaded in order to avoid glare. One of the chief difficulties in their use is in obtaining convenient outlets for connecting them.

The dome which hangs suspended from the ceiling has supplied an excellent lighting for the dining table for many years when used under the proper conditions. Its popularity is on the wane but it has served well. The dome must be hung sufficiently high in order not to interfere with the view across the table but when in this position care must be taken to conceal the light-sources from view. Some of the principles already discussed in Chapter XV apply to the dining room dome.

Although the dome provides a satisfactory distribution of light, such a result may be accomplished by means of units which are more satisfactory or modern in appearance. The ordinary shower equipped with proper pendant shades and bowl-frosted lamps may be so hung as to provide a distribution of light quite similar to that from the dome. The simple principles shown in Fig. 4 may be applied to the pendant shades of a shower. The advantage of such a unit may be shown by means of a specific case. Assume the fixture to be supplied with deep pendant shades of a dense yellow opal glass. Such a fixture may be hung high without annoying glare from the light-sources because these are concealed by the deep shades and the dominant light is downward, the spread of the direct cone of light from the aperture of each shade being determined by the height of the light-source above the aperture of the shade. The faces of the diners which are about 15 inches vertically above the edge of the table receive the warm yellow light transmitted by the shades as well as some of the unaltered light which is reflected from the table covering and other objects. The room in general under these conditions is much less intensely illuminated than the table which is a pleasing result. By means of two circuits a variety in intensity of illumination may be obtained and if tinted lamps are used some of the charm of color may be enjoyed.

Some showers are supported from the edge of an opaque disk or opal glass bowl. In the former case the fixture is not always

equipped with an outlet above this opaque disk or shallow bowl in order to obtain an indirect component but this may be done with pleasing results for appropriate occasions. The indirect component whether from an opaque or opal glass bowl is valuable in introducing variety of distribution and color of light.

Some chandeliers equipped with upright imitation candles and frosted lamps approach in distribution of light that which is obtained from the so-called semi-indirect bowl. Sometimes the shadows are objectionable and it cannot be said that this unit successfully fulfills any specific aim over the dining table. If silk shades having a highly reflecting and diffusing inner surface be placed over the frosted lamps, a considerable portion of the light is directed downward and the effect as a whole may be quite pleasing.

Representative types of units and the chief principles of lighting the dining-room have been discussed but the possibilities in lighting the dining table will be further shown by means of a specific unit designed to meet some of the modern requirements. A diagram of this unit is shown in Fig. 37. The aims were to obtain a dominant light upon the table by means of a unit possessing a modern appearance and to introduce the element of variety in distribution and color of light in a simple manner from accessories which were available in white opal glass. An opal glass bowl, 20 inches in diameter was chosen because it had a "button" in the center 4 inches in diameter. This button was ground off until a hole 3¼ inches in diameter was made and in this hole a spun metal ring *R* was fitted with a shoulder which supported it in place. An opal shade *S* which had been previously chosen of a proper depth and curvature near its aperture was held in place by the ring *R*, and the socket *A*. By means of the rod *E* the light-source could be raised or lowered, thus controlling the solid-angle of the direct cone of light *D*, which illuminated the table to a sufficient intensity. The outside of shade *S* was toned a warm yellow and the outside of the large bowl *B* was decorated by means of warm colors. The unit was hung so that there is a clearance of 32 inches between it and the top of the table.

When the center lamp is lighted the table is illuminated by means of the direct cone of light *D* and the brightness of the bowl *B* is very low owing to the double diffusion of light by *S* and *B*. The bowl *B* appears of a warm color and this tint is evident on the faces of the diners.

Incidentally it is interesting to note the details which play a part in lighting. The shade *S* was chosen with the lower part

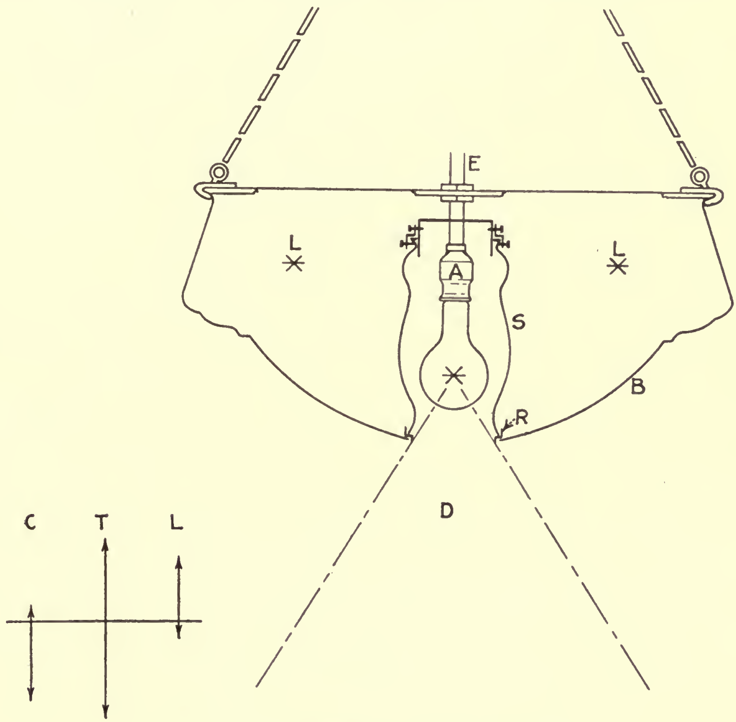

FIG. 37.—A unit designed for the dining room.

curved as shown in order that its brightness be kept as low as possible. Owing to the curvature, this lower part of *S* presents but a small projection in the direction of the light-source and hence does not become very bright. In order that the hole, which is viewed as a narrow ellipse, be of a brightness comparable to the bowl *B* the lower part of the inside of shade *S* was toned a warm gray besides being chosen of the curvature shown. Four small lamps *L* were placed outside of *S* near the

upper aperture of *B*. These are controlled by another circuit and sometimes are slightly tinted. Various obvious details of adjustment and suspension not shown in the illustration completed a very satisfactory lighting unit. The center lamp may be a modern concentrated filament type and the cone may be adjusted to fit the table-top. It was found that an ordinary incandescent lamp was very satisfactory and that the shadows due to the direct light were not as harsh as with the concentrated filament. Even when a "daylight" lamp is used in the center socket the bowl *B* will appear warm in color. It may not suit many tastes to use artificial daylight for the direct light but it is interesting to note the beauty of such color schemes as butter, paprika, and baked potato under this illuminant as compared with their appearance under ordinary yellowish artificial light. The latter quality of light, however, appears to be more pleasing in its general effect in the dining room. The element of variety is obtained both in color and in distribution of light by this fixture which is as simple as many which do not strive for such effects. The three distributions of light obtainable are shown in Fig. 37; *C* being a small upward and large downward component obtained when only the center lamp is lighted; *L* being obtained from the four small lamps; and *T* being the result of the combination of *C* and *L*.

A great opportunity lies in combining science and art in fixtures for the dining room which carry out a definite aim. Silk shades on chandeliers provide excellent opportunities especially in large dining rooms. At the present time it is necessary to design a fixture and to have it made in order to enjoy the greater possibilities of lighting over the dining table; but doubtless lighting units will be developed to meet the needs discussed in the foregoing paragraphs. At least two baseboard outlets will be welcomed in the average dining room; one for candlesticks which commonly ornament the buffet and the other for an ornamental lamp or for various accessories.

Bed Chamber.—The chief lighting in the chamber is for completing the toilet at the dresser or dressing table. Two wall-brackets, one on each side of the dresser, provide the best

general solution of this problem. Light from a central fixture does not fill the requirements at the dresser because the light must illuminate the side of the person which is viewed in the mirror and this side is usually that facing the wall. For this reason wall-brackets serve the purpose very well. Outlets should be provided for decorative lamps which may be placed on the dresser and serve a purely utilitarian purpose in the absence of wall-brackets but such lamps are seldom high enough and far enough outside the line of vision to be satisfactory for making the toilet. Two baseboard outlets placed according to the wall space should be provided in most chambers. It is well to provide an outlet in the center of the ceiling controlled by a switch near the entrance whether or not this is intended for use initially. A light-source of small luminous output concealed in a dense inverted bowl provides a pleasing illumination for many occasions in the chamber. Some of the modern units in which silk shades may be employed provide a decorative quality which is welcomed.

Bathroom.—Perhaps the best solution of the lighting in a bathroom is to provide a bracket on each side of the mirror. The luminous portions of the units should be about 5 feet above the floor because in this position there are no prominent shadows on the face. The man who shaves himself will appreciate this and there are many other reasons for such a lighting. A single unit cannot serve the purpose of lighting the face as well as two units. Owing to the fact that the surroundings in a bathroom are usually highly reflecting, glare is seldom experienced from opal lamps of low luminous output even when used without shades. However, it is easy to equip the brackets with small shades or even half-shades. These brackets usually provide satisfactory lighting for the entire room.

Den and Study.—The principles discussed in the lighting of a living room apply equally well to the den and to the study. Perhaps one purely utilitarian portable lamp may be desired in these cases but the lighting of such rooms is so much a matter of taste that it cannot be discussed further with much profit. Portable lamps are exceedingly adaptable to the lighting problems in these rooms.

Kitchen.—The combination fixture which is so often found in kitchens projecting downward from the center of the ceiling is usually a nuisance and is too low to illuminate the entire room satisfactorily. When the light-source is low a person is generally obliged to work in his own shadow because the various work-places, including the stove, are usually located near the walls. If the kitchen is small an electrical lighting-unit close to the ceiling and in the center is fairly satisfactory. The gas units which cannot be placed at the ceiling may be located on the walls and electrical wall-brackets may be used to supplement the central unit. Control from wall-switches is very convenient.

These are the most important aspects of residence lighting, although lighting units in hallways, closets, vestibules, on porches, in the basement and in the attic must be ranked as conveniences and real necessities in most cases. These need not be discussed because the problems are not difficult. Ceiling fixtures will be found most satisfactory in many of these cases. The element of taste is such a factor in residence lighting and there are so many variables that it has been the aim to confine the discussion largely to general principles and to bring to the attention some of the mistakes which are commonly made. Residence lighting is a field which is undeveloped from the broad viewpoint of lighting. First the multitude must be awakened from their indifferent attitude and taught to appreciate the wonderful potentiality of proper lighting in contributing to the welfare and happiness of mankind.

In the preceding paragraphs the discussion has been confined to general principles of residence lighting, but in closing, it appears of interest to suggest some of the possibilities in lighting which certainly will find wider application as the pleasures from lighting effects become more fully appreciated. During the construction of a residence many novel applications of lighting may be incorporated not only to obtain more pleasure and variety in lighting but to convert unattractive nooks or wall-spaces into pleasant places. For example, it is not too theatrical to set a large decorative panel of opal glass in the ceiling of a dining-room and to install red, green, and blue lamps

above it in a space which has been painted with a permanent white coating. If these lamps are controlled by means of three sliding rheostats concealed in the wall any desired tint and intensity of light may be obtained. How such a control of light may be utilized in adapting the lighting to the spirit of the occasion is left to the imagination of the reader. The cold tint of "moonlight," the warm glow of yellow light, and many other effects of various intensities may be obtained. Surely the cost of such an installation is not out of proportion to the enjoyment of it in the more pretentious residences.

A gloomy hallway or alcove may be equipped with a horizontal lattice placed a foot or two from the ceiling and upon this, artificial vines may be entwined. Small lamps in reflectors may be placed along the wall above the lattice and the light may be directed to the ceiling. The color of the sky or the usual "moonlight" color may be obtained by using color-screens over the apertures of the reflectors or by painting the ceiling with the desired color. This indirectly lighted ceiling as viewed through the vine-covered lattice will appear like the sky. The same idea may be carried out in a high vertical window by moving the window to the outer portion of the frame and by covering it with a stained cardboard. Tubular reflectors may be used inverted and uniformity in the brightness of the background may be obtained by a graduated reflection factor easily obtained by the use of a black water-color. The simplest method of obtaining the desired tint is usually to color the reflecting surface which is to be viewed. Many occasions in the home may be agreeably lighted by means of the faint light from such an artificial "moonlight" window. Doubtless there are conditions when a warmer light of higher intensity would be desired.

Unique and pleasing effects may be obtained by concealing light-sources in imitation flower-boxes hung on the walls in the sun room or dining room and perhaps on the porch and in the living room. Many decorative spots of light may be obtained by concealing light-sources in vases and in other appropriate decorative objects. A jardiniere on a pedestal provides an excellent place in which to conceal a reflector and

a fairly large light-source from which a large room may be indirectly illuminated. Artificial vines may be draped from the jardiniere very effectively. Vases containing lighting units may be placed upon the mantle, upon bookcases, or upon the piano and from these very pleasing indirect illumination may be obtained. In the sun room a central indirect fixture consisting of a suspended basket containing an artificial foliage plant provides an appropriate place for concealing a light-source. These are a few suggestions which are worthy of more extensive use and the householder who awakens to the innumerable possibilities of lighting will be agreeably surprised at the pleasures innate in lighting effects adapted to the surroundings and to the various occasions.

CHAPTER XVII

COMMERCIAL LIGHTING

It has been stated in foregoing chapters that the aim of this volume is chiefly to discuss principles and to present ideas which have permanent value instead of tabulating data and presenting specifications which are subject to more or less change as light-sources and lighting units are developed and improved. The engineering data pertaining to lighting equipment may be obtained from manufacturers and dealers and these form the basis of much of the literature on lighting; however, discussions of the broader principles and of many interesting details which form the basis of creative lighting-practice are relatively rare and are not readily accessible to a great percentage of those interested in lighting. Fortunately the present aim makes it possible to group various aspects of lighting-practice into a few classes and therefore under the title of this chapter all kinds of stores and show-windows will be discussed more or less as a whole.

In stores the laying-out of outlets and the determination of the consumption of gas or electricity per square foot of floor-area for various kinds of lighting systems and environments are engineering problems whose solutions have been fairly well standardized. Experience and observation of other installations make it possible to choose satisfactory lighting units especially when a degree of freedom usually exists in the choice of lamps of a satisfactory luminous output even after the installation of the lighting accessories has been made. Gross errors in the engineering of lighting are far rarer than failures to recognize other pertinent factors and to utilize the advantages of details which are not commonly considered in an engineering solution of the lighting problem.

In viewing the field of lighting broadly it is easy to conclude that the purely engineering aspect of lighting has been much

better taken care of than the artistic, psychological and purely scientific aspects. The engineer has kept abreast of the times and much lighting progress is due to his efforts but when he alone attempts to be responsible for utilizing the entire potentiality of light it is found that much of this is unused. It is just beginning to be recognized generally that there is a vast portion of lighting which is not engineering and cannot be successfully practiced by the engineer who has not studied the various other aspects of lighting. This criticism applies to commercial lighting as well as to nearly all fields of lighting-practice.

The engineer may be mildly criticized for bringing into lighting-practice the word "efficiency" for its usage has far outgrown its intended purpose and has done much to hamper the utilization of the greater possibilities of light. Efficiency is an excellent slogan to apply judiciously to lighting apparatus because it is folly to waste light before it leaves the unit or by permitting it to be lost upon surfaces which are not of interest or where it is not desired. But to apply the term "efficiency" to a lighting installation as a whole by determining the ratio of the lumens incident upon a certain "work-plane" to the total lumens emitted by the light-sources is misleading and even unjustifiable and is in reality an admission that only the engineering aspects are being considered. It is also misleading and unjustifiable to consider the efficiency of a lighting installation to be the reciprocal of the cost ot operating it. If the term must be used let it represent, in the broader sense, the ratio of satisfactoriness to cost. It may surprise some illuminating engineers to learn that the merchant does not always hold cost of lighting above satisfactoriness. This has been well exemplified, for example, in the propagation of artificial daylight for commercial lighting. Notwithstanding the lower luminous efficiency of artificial-daylight units and the other factors tending to increase the cost of such lighting, many merchants have adopted artificial-daylight illumination. This is an excellent example because no other factors entered in many cases except quality of light and increased cost of lighting. Increased satisfactoriness balanced increased cost. The

illuminating engineer has introduced the word "efficiency" into lighting parlance but recognizing the deterrent effect of its narrow usage he will do much to alter its meaning when applied to lighting as viewed broadly. The greater possibilities of lighting cannot be employed without reducing the efficiency in its narrow sense but when these possibilities are realized the efficiency in its broad meaning will be increased.

Any of the various systems of lighting will doubtless find suitable places among the extensive variety of stores. It appears that the enclosing unit or the so-called semi-indirect unit is more generally satisfactory for store-lighting than other types of units when both attractiveness and utilization efficiency are considered. Direct-lighting fixtures of deep opal or prismatic shades appear to be satisfactory in many stores especially when bowl-frosted lamps are used or when the light-sources are shielded from view. Unless the fixtures are artistic it does not appear that direct-lighting fixtures with open shades can contribute as much to the attractiveness of the store as enclosing units. The latter usually make it possible from an engineering standpoint to use light-sources of high luminous output, thus contributing to efficiency as well as to attractiveness. Some classes of stores, for example, jewelry stores, appear more attractive under the glittering effect of many light-sources. Jewelry loses much of its attractive glitter under highly diffused lighting and it is a legitimate use of light to display goods in the best manner. In such cases direct-lighting units with open pendant shades may be used to screen the sources from the observer. Incidentally, the lighting of diamonds and other jewels is an important matter both as to quality and distribution of light. The dealer prefers to buy such goods under a light of daylight quality and of a distribution such as obtains from a patch of sky. It is impossible to judge a diamond with certainty under the glittering light from a myriad of yellowish light-sources.

As has been stated it appears that a fairly diffused lighting generally renders a store more attractive as a whole and illuminates shelving and various displays as well as the decorative features of the interior. Shadows are necessary for good seeing,

hence the enclosing unit or the semi-indirect unit serves the purpose very well. Besides the other objections which have been mentioned regarding the multiple-unit direct-lighting fixture, the multiple shadows are sometimes annoying. The purely indirect system does not appear to be generally applicable to stores although there are classes of stores where it is very appropriate. For example, a furniture store with its mass of large objects, many of which have glossy surfaces, may be lighted satisfactorily by indirect systems.

The appearances of colors are of primary importance in nearly all stores and inasmuch as illuminants are now available for general lighting which approximate daylight in spectral composition this aspect is worthy of discussion. In Chapters X and XI artificial daylight and its applications have been discussed but there are certain points which may be brought out here. As discussed in those chapters an illuminant of daylight quality is the logical illuminant for viewing colors and the daylight appearance of nearly all objects is the one on which judgments will usually be based. Of course in the case of an evening gown which is to be worn only under artificial light its appearance under this illuminant is of chief interest; however, curiosity usually leads to a desire to view even such a gown under daylight. No one would think of forming a judgment of a colored object under a red illuminant in which only the yellow, orange, and red rays existed. In a rough manner ordinary artificial light commonly used in stores may be considered to lie between this red illuminant and daylight in quality because in it the yellow, orange, and red rays are abundant and the violet and blue rays are relatively rare. The quality of ordinary artificial light is purely accidental and has little value as an illuminant for color-discrimination except on the basis that the objects which are purchased under it are to be viewed under it. Not only has our judgment of color developed under daylight illumination and our color-sense evolved amid the environment of daylight but we still remain "daylight" individuals to a dominating degree. In fact, it may be said that daylight is a part of the scheme of creation. For these reasons artificial daylight finds a field in commercial lighting.

In order to be able to deal definitely with the problems of color the lighting specialist should be acquainted with the chief principles of the science and art of color. One of the most annoying conditions for discriminating colors is that found in many stores where daylight and artificial light intermingle though coming from different directions. For example, if a piece of colored goods, especially a glossy silk, be examined under the downward light from an artificial lighting unit and at the same time daylight is arriving in a horizontal direction or nearly so, it is difficult to form a conception of the color of the goods. Such an experiment is convincing to a merchant. Means for helping to overcome any objection due to the coldness of artificial daylight have already been discussed. This objection is a result of prejudice or habit and it is not difficult to overcome both by the presentation of facts and by resorting to illusions. It should also be remembered that stores are frequented chiefly in the daytime and if it is lighted by artificial daylight it will not be considered cold in appearance by the average customer, but will be unconsciously considered to be illuminated most delightfully by an abundance of daylight. This is the psychological effect on many customers as determined by actual investigation. Care should be taken to avoid the use of yellowish tints and shades too predominantly on the ceiling if much light is reflected from it to the workplane because this light would be colored by selective reflection. This alteration may be sufficient to change the artificial daylight materially toward the ordinary yellowish artificial light. For accurate color-matching, various artificial-daylight units are available which may be placed above counters or in rooms especially designed for the purpose. Some stores have been equipped with rooms side by side lighted by ordinary artificial illuminants and by artificial daylight respectively. These are used for viewing gowns, furs, cloaks, etc.

In one instance, at least, a store has been provided with a room containing foot-lights and border-lights equipped with movable color-screens for the purpose of viewing theatrical costumes.

Many special distributions of light are applicable to specific

cases in stores. For example, rug-racks have been lighted by means of borders of lamps in reflectors. In one case a merchant was found to be displaying rugs under amber lamps which made the rugs appear somewhat faded and oriental-like but the illegitimacy of such a procedure is obvious. Nearly everyone can recall instances when a rug or other colored object which had been selected under artificial light in the store has presented quite a different appearance under daylight illumination in the home. Similarly such objects often appear widely different in the home in the daytime or at night. These are practical examples of the importance of quality of light in the selection of colored objects.

The problem of show-case lighting is largely one of engineering, that is, in the design of small reflectors and in obtaining light-sources of sufficiently low luminous output for illuminating the small areas in show-cases. Various excellent reflectors are available but the chief difficulty is encountered in obtaining modern light-sources of small enough wattage which have the desired color-value. In stores illuminated by artificial daylight sometimes an attractive effect is obtained by lighting the cases with ordinary illuminants, the warm tone being an attractive contrast with the general lighting. The general principles of show-case lighting are similar to those of show-windows but the possibilities in the latter are much greater.

The engineering principles of lighting show-windows are largely a matter of directing the light downward and toward the rear of the window. The selection of the type of reflector depends upon the relative dimensions of the window. For a high shallow window it is obvious that a more concentrating reflector is necessary than for a low deep window. Engineering data and rules are obtainable from manufacturers of lighting equipment so space need not be given to a discussion of this aspect. The units are logically placed along the upper front border of the window and are shielded either by a permanent opaque portion of the front or by means of a valance but various other arrangements of light-sources are also in use.

The primary object of a show-window is to attract attention and to display goods. In many respects it may be considered

to be similar to a stage and hence it should be highly illuminated as compared with the exterior surroundings. For this reason there can be no fixed standard of illumination intensity. A show-window on a "white-way" street should be illuminated much more intensely than one on a relatively dark side street. The light-sources should be concealed and the whole effect should simulate a stage-setting. Incidentally those numerous show-windows in which glaring light-sources greet the observer, unwittingly simulate the "glare" lights which are sometimes used to blind the audience in a theatre when a quick change of setting is made without lowering the curtain. The observer sees the display unsatisfactorily if he possesses the courage to withstand the glare of such exposed light-sources so common in the lower grade show-windows.

Show-windows may be provided with top-lights, foot-lights, and side-lights depending upon taste and requirements. The top-lights are indispensable for most show-windows. The foot-lights may be criticised from the viewpoint of unnatural direction of dominant light although they are of advantage in providing a diffused light for illuminating the shadows. In many cases the theatrical effects obtainable from them justify their use. Side-lights, if they can be successfully concealed, also provide additional possibilities in lighting. Corner-windows present some difficulties in concealing the border units but deep reflectors have eliminated this difficulty to some extent. In some cases stationary vertical louvers have been installed between the units with excellent success. It is not unusual in show-windows of high-grade department and dry-goods stores to provide several circuits and movable color-screens; and rheostatic control for the purpose of obtaining beautiful color-effects may be used advantageously. Base-board and floor outlets are convenient for obtaining special effects from portable lamps. Some use has been made of pendant fixtures in the show-window, including all kinds from direct to indirect and many windows are lighted through ceiling skylights. These methods are appropriate with some settings but the general case is solved best by upper border-units near the front of the window.

The background in show-windows is important from the viewpoint of good lighting conditions and of general psychological effects. It should be of a dull finish otherwise it will act like a mirror and reflect images of the light-sources toward the observer. Many beautifiul show-windows with glossy backgrounds are robbed of some of their artistic value by the reflection of images of the light-sources. The color of the light influences the color of the goods and besides the spectacular and artistic uses of colored light, artificial daylight is used quite extensively in show-windows. The considerations are quite the same as in using artificial daylight in the store; however, the psychological effect of a background of warm colors may be advantageously employed. Most of the light on the goods is directed toward them by the reflectors and the goods ordinarily occupy but a portion of the entire show-window scene. If a warm background is employed the goods are still lighted with nearly the same daylight quality though the whole scene is considerably "warmer" owing to the psychological effect of the large area of background. Of course some light is altered in color and finds its way to the goods but this sacrifice can be made if necessary in order to have light of a fair daylight quality on the goods and yet retain at night the attractive warmth of the scene as a whole. Such backgrounds are easily obtained by the use of draperies of deep shades of the desired color.

The show-window is often unsatisfactory in the daytime owing to the images of external objects reflected from the plate glass. An attempt has been made to avoid this difficulty by using a concave glass as viewed from the exterior. This is not completely successful because regardless of the orientation of the glass there is usually a bright reflected image which reaches the eyes. Attempts have been made to increase the intensity of daylight illumination in the window by the use of prism glass in the ceiling and in the front above the window. These may possibly aid in reducing the prominence of the images reflected from the glass through an increased intensity of illumination inside the window but ordinarily they do not do this to an appreciable extent. Such prism glasses are valuable aids in the lighting of show-windows in special cases. Awnings

appear to be the most practicable means of reducing the annoyance due to reflected images but these cannot prevent the reflection of the image of the bright sidewalk. There appears to be no practical method of overcoming these difficulties in the show-window which directly faces the street as long as the exterior objects are bright but the awning greatly reduces the annoyance of reflected images if it is not too bright, that is, if not too highly transmitting.

In show-window lighting many of the possibilities in the distribution of light, shade, and color may be applied. Relative dark backgrounds provide striking contrasts with the objects which are displayed and on the other hand, backgrounds of relatively high reflection-factor lend an airiness to the picture which is very charming for certain settings. Sometimes a single object in a window amid unglazed or velvety surroundings provides an extremely attractive display especially if this object is strikingly illuminated. Shadows are necessary on objects for it is largely the modulation from high-light to shadow which models the objects. Even the nuances of light and shade on a draped silk fabric provide a more artistic picture than the uniformity and flattened effect of highly diffused lighting. Footlights have value in controlling the intensity of the shadows which are due to the directed light from the upper border-lights. A fact gleaned from the study of light and shade is that vertical and symmetrical shadows are not generally as artistic as oblique and asymmetrical shadows. However, under the uniform spacing of border-lights asymmetrical distribution of light cannot be obtained. An ideal arrangement of outlets for the show-window is to have these spaced entirely around the four sides of the vertical front of the window and to have the lamps concealed. By means of such an arrangement the lamps need not be uniformly spaced but may be shifted into various sockets in order to obtain the desired dominant direction of light. For artistic effects the lighting in a show-window does not need to be uniform for all settings. Outlets should be provided generously and in order to be prepared for special effects as many as three intermingled circuits may be provided. These may be equipped with color-screens and controlled by means of

motor-driven rheostats in order to obtain attractive mobile-color effects.

The lighting accessories which are available for show-window lighting are trough reflectors usually with silver reflecting surfaces; enameled, aluminized, and silvered opaque reflectors; prismatic and opal glass reflectors; portable lamps and various types of ornamental fixtures. In general, the silvered and prismatic reflectors for single light-sources are the most satisfactory for concealed border-lights at the top of the window although the accessory should be selected to meet the conditions. Data as to distribution, spacing, etc., are readily obtainable from manufacturers.

The applications of lighting need not be confined to that of ordinary practice; in fact, the greater possibilities are found in utilizing lighting effects more nearly approaching those of the stage. That lighting can be made to provide striking and attractive effects quite appropriate to the display will be shown by discussing a possibility. Let us assume an ordinary window in a large department store but a double casement window (without glazing) will be supposed to be provided in the center of the background of the window. Four feet behind the rear of the window another partition may be erected and upon this any scene painted on canvas may be supported. This scene may be illuminated by means of border-lights concealed behind the first wall or the background of the window. By means of tinted lamps this scene may be lighted just as it would be on the stage and, if desired, mobile-color effects may be obtained by means of motor-driven rheostats. Let us suppose, for example, that winter furs are being displayed as is usually the case during the hot days of autumn. Surely the psychological effect of lighting may be used to advantage in order to interest purchasers of furs when the weather does not emphasize their necessity. With this preparation the scene may be set in the following manner. The window may be furnished as an interior room lighted by means of a floor-lamp and a very dim diffused light from the border-lights. The figure of a woman is standing gazing out of the open window at a snowy mountainous landscape lighted by means of lamps tinted a blue-green. She

wears a fur cloak thrown open but muff and stole lie carelessly upon the library table. To carry out the idea of a fur display, fur rugs may be used on the floor. Lighting is the principle factor in the effect of this scene. The warm glow of the interior is contrasted with the coldly-lighted snowy scene and by suggestion such a setting would surely awaken more interest in furs in August or September than a display which is illuminated in the ordinary manner. Similarly as goods are commonly displayed out of season the latter may be vividly brought to mind by means of the appropriate setting and lighting. Innumerable possibilities in lighting await the show-window expert who comes to the realization that the window is a stage, and should be provided with the simple equipment which makes it possible to display goods and to attract attention by utilizing all of the potentiality possessed by distributions of light, shade, and color.

CHAPTER XVIII

LIGHTING IN PUBLIC BUILDINGS

Those who are entrusted with the lighting of public buildings have a civic duty to perform in safeguarding vision and life. In the case of a decorative interior there is a further responsibility in revealing the beauty of the interior by combining science and art in lighting. In the schools of this country twenty million pairs of eyes, immature in growth and in function, are daily being subjected to the strain of close work. Many museums are filled with art treasures and objects of historical interest and to display these properly the lighting must be well done. In the theatre and in other auditoriums where audiences gather it is a duty to safeguard lives and in this respect ordinary and emergency lighting systems are important factors. In many beautiful interiors of public buildings the lighting is not doing its part though there are relatively few who feel capable of criticizing and often there is no definite place to submit a complaint. In general, the public goes about its business and the unsatisfactory condition remains. The architect should avoid such mistakes by soliciting the aid of the lighting specialist. As an example of the foregoing a public building may be cited in which a few large mural paintings decorate the walls. The initial cost of these paintings was nearly one hundred thousand dollars, but largely due to the character of lighting systems, these paintings cannot be satisfactorily viewed. In this chapter the lighting of a few classes of public buildings will be discussed briefly. The relation of lighting and architecture will only be touched upon as in other chapters because this subject is treated separately in Chapter XIV.

Schools.—The eyes of school children are immature in growth and, therefore, are subject to permanent disorder through misuse. Nearsightedness is a common defect caused by maintaining the eyes in a position too close to the work as is necessary

under bad lighting conditions. Records show that the percentage of school children possessing defective vision increases with their age under improper lighting and decreases under proper lighting. The lighting specialist should view his problem from the broad aspect which includes vision and the appearances of objects or of settings as a whole. In the schoolroom the problem of safeguarding vision does not end with the spacing and design of the lighting units, for it involves the character of the surroundings and other factors. Daylight is usually of greater importance in schools than artificial light but the latter is becoming more and more necessary especially in city schools. The daylighting of schoolrooms is being done fairly well at the present time because it has been extensively studied by architects and engineers. For sanitary reasons it should be possible for sunlight to penetrate as many rooms as possible, although the windows should be equipped with diffusing shades for controlling the daylight while the rooms are occupied. The most approved shade is a double roller at the meeting rail of the double window so that one shade may be pulled upward and the other downward.

There is still some question whether or not a classroom should have windows only on the side to the left of the pupils or on the rear side as well. However, unilateral lighting appears to be satisfactory for rooms less than 20 feet in width. The window-area should not be less than 20 per cent. of the floor-area and the width of the room should not be greater than twice the height of the top of the window.

The light-value of a window depends upon the brightness of the sky, the amount of sky visible at a given point, and indirectly upon the reflection-factors of the surroundings and upon the dimensions of the room. The upper part of the window is more effective in lighting the interior than the lower part so that the window area should extend close to the ceiling. Observations in well-lighted rooms show that under average conditions of daylight, satisfactory illumination is usually obtained when the visible sky subtends a minimum vertical angle of 5 degrees at any work-point. In cases where the horizon is obstructed the window-area should be larger

than the minimum recommended and prismatic glass may be utilized for directing the light into the room. Light-courts should have high reflection-factors. The light-value of a window may be determined at a given point by multiplying the area of the window through which sky is visible by the sky-brightness and dividing by the square of the distance from the window to the point of interest. This gives the minimum value of illumination at this point because some light is contributed by reflection from various surfaces. This inverse square law does not hold unless the distance is several times the maximum dimension of the apparent source. The brightness of a clear sky may be taken as 1 lambert or the approximate equivalent of 2 candles per square inch. Large rooms dependent upon natural light should have light on two sides preferably on the left side and on the rear of pupils as seated.

In schoolrooms, general lighting should be adopted in all cases. When the ceilings are high, direct-lighting may be satisfactory if the shades are deep and highly diffusing. Maximum brightnesses and brightness contrasts should be kept as low as possible and should not exceed those recommended on page 33. Semi-indirect lighting by means of units equipped with dense opal glass is generally the most approved system for ordinary classrooms of small and medium sizes. In large classrooms, auditoriums, etc. the best solution is often found in lighting from concealed sources or by indirect systems. Localized lighting by means of units placed on desks, tables, and work-benches or hung near machines is generally condemned. In special cases such a system is satisfactory if the light-sources are well-shaded and the units are fixed in an unalterable position. However, there appear to be few cases where general lighting is not justifiable from the standpoints of safety and of better lighting. The illumination on the plane of the desk-tops and on other work-planes should be as uniform as is practicable. This is obtained by a generous distribution of outlets. If there is a definite directedness to the light this component should fall from the left of the pupil (assuming general right-handedness) in order that the shadow of the hand will not be annoying in writing.

Glossy surfaces of paper, woodwork, desk-tops, walls and blackboards are likely to cause eyestrain because of the specular reflection of images of the light-sources, therefore dull surfaces are recommended. Blackboards should be placed in such positions that no images of light-sources will be reflected toward the pupils. Simple laws of reflection may be applied in order to determine a correct position for a blackboard. In cases in which glare of this sort cannot be otherwise avoided it is well to provide auxiliary illumination from local artificial light-sources properly screened from the pupils. The blackboard area should be the minimum which may be required.

Proper distribution of illumination and brightness greatly dominates in importance over quality of light and distribution of color in schoolrooms; however, the latter are of importance. The more restful colors such as cream, shades of buff and olive green should be used on the larger areas. In certain activities artificial daylight is being successfully used. Botany classes at night are better conducted under artificial sunlight and this quality of light is also in use in art rooms, sewing rooms, print shops, and in laboratories devoted to chemistry and domestic science.

Museums.—The problems of lighting in museums varies with the character of the exhibits and the dimensions and construction of the rooms. In a large museum the lighting specialist finds a variety of interesting problems and the potentiality of lighting should be drawn upon to the fullest extent in order to illuminate the objects properly, for their value should be due to their appearance more than in the mere possession of them. This entire field is open to the lighting-artist as well as many other phases of lighting. In order to bring out the chief principles in the lighting of museums, a few different types of exhibits and rooms will be considered. However, the problem of quality of light may be discussed in general before taking up specific cases.

It cannot be denied that daylight is generally the proper quality of light for the illumination of objects which are exhibited in museums and therefore artificial daylight should be widely adopted in such places. This has been done in a

number of museums with exceedingly satisfactory results. However, there arises the question of the best quality of daylight for museums. Northern exposure is desired by many but southern exposure appears to be preferred by a still greater percentage of persons who have given the matter consideration. In such considerations, however, quality of light has not been the only factor, for constancy has also been of some weight. After a prolonged study of this matter it appears, when a judgment is rendered on quality alone, that the quality of light entering skylights and windows of southern exposure in this hemisphere is preferred by a large majority of artists and others qualified to render an authoritative opinion. For this reason it is legitimate to warm up the light which enters north windows by means of light tints of yellow in the curtains or draperies which cover the windows.

This is a fortunate condition for, owing to the demands of economy, the more practicable artificial-daylight units which are available for general lighting more nearly simulate the quality of light from the sun than from the north sky although this quality of daylight renders colors quite satisfactorily. Even in the daytime an art museum with neutral walls may be rather cheerless so that the wall-coverings best suited to such interiors should generally be a warm gray. Backgrounds of vivid colors are improper for exhibits of most works of art if the appearance of the latter is primarily considered, because the appearance of an object is affected by its environment. For example, a white surface viewed against a pink background appears of a greenish hue and all colors are affected by the color and brightness of the surroundings. The gilded frames and the warm gray backgrounds also tend to produce a more cheerful interior under the illumination from artificial-daylight units.

In the lighting of paintings galleries there are other fundamental desiderata besides daylight quality of light; namely, that the brightness of the floor and ceiling should not be too great in comparison to the walls; that the component of light vertically downward should not be large in comparison with that directed toward the space on the walls upon which pictures are to be hung; and that there should be no images of

bright light-sources or of other areas reflected from glazed or varnished pictures directly into the eyes of an observer at a reasonable viewing distance. The brightness of the floor may be reduced to the proper value by reducing its reflection-factor or by employing coverings of low reflection-factor. Unless the ceiling is of glass the same expedient may be applied to it but in the case of glass it is necessary to employ one which is not too diffusing in order that it may not become a secondary

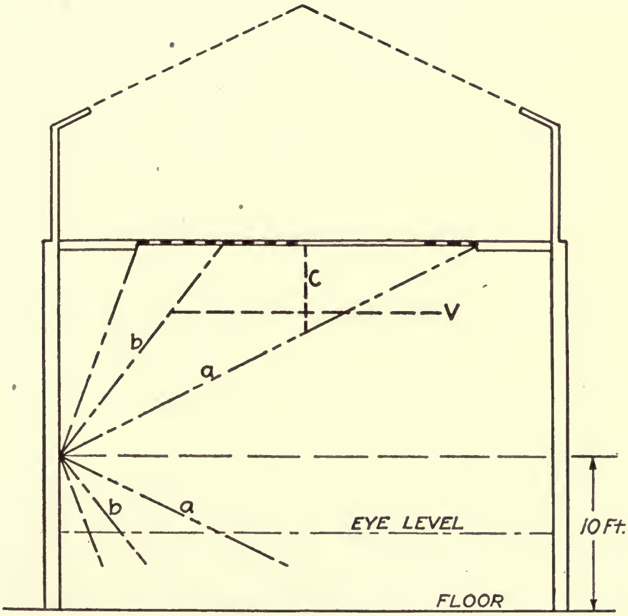

FIG. 38.—Some principles applied to a paintings gallery.

source of a brightness greater than that desired. The proper glass is of great importance because it must also serve the purpose of obscuring the attic structure. Rough refractive glasses appear to be the most suitable.

In order to ascertain the conditions which will not result in annoying images reflected into the eyes of the observer, the simple law of reflection, *a*, Fig. 12, may be applied. If the opposite walls and ceiling are bright and if the latter is too extended, there is no escape in a room of ordinary dimensions, from annoying images reflected from glazed pictures. This is shown diagrammatically in Fig. 38 in which the dimensions are

satisfactory for avoiding this difficulty. The eye-level may be taken as 5 feet above the floor and the maximum height of any portion of a picture as 10 feet. If the ceiling is high and not too extensive it will be found that the image of the farthest point of

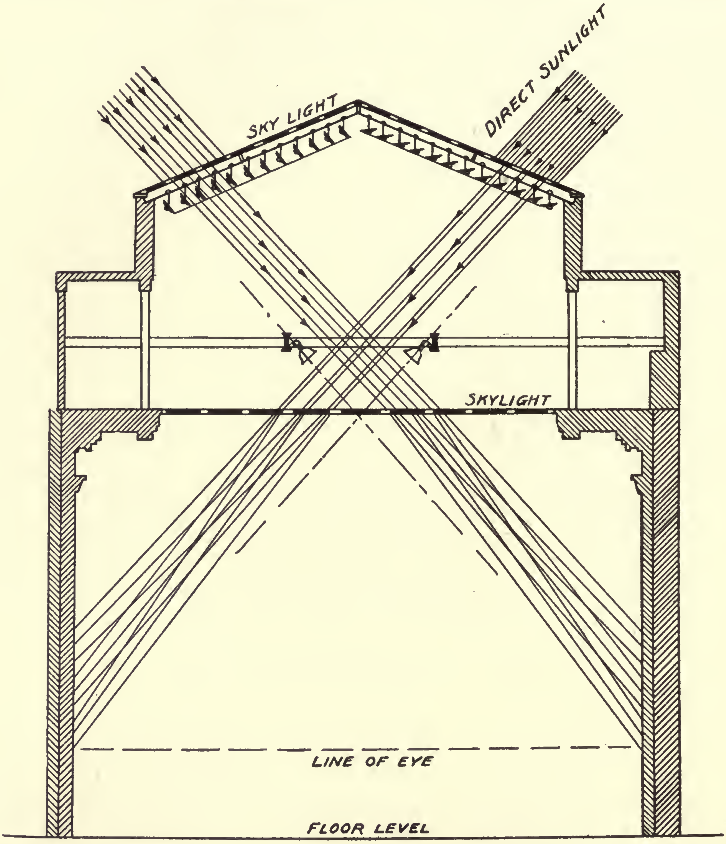

FIG. 39.—Illustrating some principles of light-control applied in the Cleveland Museum of Art.

the sub-skylight glass will not be reflected into the eyes of an observer unless he is close to the picture. If the ceiling is low or too extensive an opaque curtain may be hung from the ceiling as *C* (or several if necessary at different points on the ceiling) in order to eliminate this difficulty. The use of an opaque or dense diffusing velum *V* is also an effective expedient. However, these are usually makeshifts which are unsightly.

The velum possesses the desirable feature of reducing the downward component and this idea may be effectually woven into the architectural scheme of a gallery although it has rarely been done.

The reduction of the vertically downward component in galleries which is so tiring to the eyes may be accomplished by using clerestory windows instead of a horizontal sky-light and by means of louvers in the case of roof and sub-skylights. They may be placed in various positions depending upon the conditions. In Fig. 39 is shown an application of adjustable metal louvers close to the roof skylight in the Cleveland Museum of Art. By means of these the illumination on north and south walls may be equalized and the vertically downward component may be reduced considerably in comparison with that which is directed toward the wall-space on which pictures are hung. The artificial-daylight units were placed as shown in this museum and the light was directed toward the walls by means of projectors. A difficulty in artificial lighting usually is encountered in concealing the units or in devising artistic units which direct the light toward the walls. It does not appear that the limit of ingenuity has been reached in the design of chandeliers or of other units which may beautify a gallery and at the same time direct light toward the walls. Low vertical windows are not justifiable in paintings galleries owing to the sacrifice of wall-space and to the unavoidable reflection of images of bright objects and of the sky from many of the paintings directly into the eye. There are many other details in the lighting of paintings galleries which become apparent after due consideration of the conditions in a specific case.

In sculpture galleries the problem of lighting is quite different from the preceding one. The chief defects in the lighting of sculpture galleries are found in the multiple shadows due to several light-sources—either windows or artificial units—and the flattening effect due to the diffused light from an extensive skylight. In the lighting of sculpture it should be noted that the position of the light-source determines the direction of the shadows; the solid-angular extent of the light-source at a given point determines the character of the shadow-edges; and the

diffused light from the surroundings determines the brightness of the shadows. Individual rooms or alcoves in which the object may be properly oriented with respect to the light-source and in which the lighting may be somewhat controlled represents the ideal in the display of sculpture. However, such a condition is rarely practicable so that the objects may be placed judiciously in a sculpture gallery or in various advantageous positions in the museum. In general, as few lighting-units as possible should be used in a sculpture gallery and the skylight-area should be made of such an area that its solid-angular extent is not too great to cause flattening of the objects or too small to admit sufficient light. If a sub-skylight is used it should be satisfactory to flood this with light for the artificial illumination of crowded sculpture exhibits. The foregoing principles are the chief ones but most details must be worked out for each specific case.

In the display of various other objects the same general problems are met. In rooms containing many glass cases the simple optical law of reflection should be considered in aiming to avoid annoying reflected images. Vertical glass sides through which objects may be viewed generally are free from this annoyance if the artificial lighting units are hung high. It is possible to view the objects through three vertical glass sides of a case if windows are confined to one side of the room.

Many valuable objects of delicate colors are found to fade under daylight illumination and insurance against this may be obtained to some extent by using certain artificial-daylight units owing to the lower amount of ultra-violet energy per lumen as compared with that of daylight. Owing to the many difficulties encountered in the control of daylight, to the cost of construction of extensive skylights, to the maintenance, and to the fuel consumption directly attributable to large areas of glass, it would not be surprising to find natural daylight gradually giving way to artificial daylight in the illumination of art treasures and other valuable objects.

These are only a few of the chief points pertaining to the lighting of museums but there are many interesting details. This is a field worthy of the interest of the lighting specialist

because it supplies many-sided problems which draw upon his scientific and artistic ability.

Auditoriums.—The problem of lighting in such interiors must be viewed from the standpoint of the audience primarily although there should be some consideration for those on the platform. If the interior is particularly decorative the lighting effects should be in harmony with the architectural and decorative scheme and the fixtures, if there are any visible, should also be in harmony with the whole. Various general types of lighting are applicable to auditoriums depending upon the conditions. It is perhaps true that in general indirect lighting from concealed sources is the most successful from the standpoint of eye comfort and many beautiful effects have been obtained by this system. If direct or so-called semi-indirect units are used they should be hung high and the primary light-sources should be effectively screened from view. Glare and discomfort is experienced from units of high brightness in comparison with their backgrounds even though an image of them is not focused upon the retina. In other words, the upper eyelid may screen the source from the retina but the glare due to a high intensity of illumination on the eyelid is quite annoying.

The intensity of illumination in the auditorium should be controlled by means of switches and in many cases rheostatic control is desirable in order to change the intensity gradually. Many beautiful effects of color can be utilized in some cases quite appropriately. Emergency lighting and exit-lamps should be connected preferably to an auxiliary service which is independent of the main supply in order to insure the safety of the audience at all times. Special lighting should be provided for the platform in order that the speaker may be more intensely illuminated than the audience. If enclosing units such as lanterns are used it is practicable to have the side and rear panels of denser diffusing glass than the front panels and various other units may be devised to give an asymmetrical distribution of light.

In auditoriums, windows are best placed on the two sides of the audience in order to free the speaker and the audience from

the ordeal of facing windows. Ceiling skylights may be used successfully and shades should be available for controlling the daylight.

Churches.—All of the problems of auditorium lighting are found in churches with many additional ones. In attacking a problem of lighting a church in which the architectural scheme is such an important aspect it is well to be familiar with the historical development of the particular type of architecture and with the characteristics of the particular creed so that the lighting effect may be appropriate for the spirit of the interior. The lighting should be dignified, impressive and congruous and the fixtures, besides being of proper utilitarian value, should be in harmony with the period or style of architecture. No field of lighting exemplifies the expressiveness of lighting effects more than that of church-lighting. Few churches should ordinarily be illuminated to a high intensity for dim light is conducive to meditation and prayer and a concentration of light on the chancel tends to focus the attention there. The lighting should be ecclesiastical and should inspire reverence by its solemnity. Some churches have ceilings of low reflection-factor and this loftiness of the ceiling should not be destroyed by light. On the other hand, in some of our modern churches the ceiling and walls are of high reflection-factor and light diffused over all the areas appears to be symbolic of the cheerfulness which appears to be a dominant note in the creed. In this field the charm and expressiveness of tinted light may be effectively utilized but the color should be so faint as to be felt rather than seen.

In the case of natural lighting the windows should be preferably on the two sides of the audience. Windows in the chancel should be as high as possible and of deeply stained glass.

The artificial lighting of churches may be of any of the appropriate types if proper care is taken to avoid high brightnesses and brightness-contrasts. In the case of high ceilings, chandeliers and other direct lighting units may be satisfactory but with extremely low ceilings indirect units or other means of concealing the light-sources should be adopted if possible. The church is ordinarily a beautiful interior and the lighting

units should be placed so as not to obscure any of the important details. If there is a gallery the units should be hung sufficiently high so as not to be annoying to the occupants. Perhaps no other phase of lighting calls for as many special designs of fixtures, relatively, as church-lighting in order to meet the many different conditions.

The altar is difficult of treatment but its architectural construction sometimes permits the speaker to be illuminated by units concealed behind a cove on the sides. In some churches electric candles are in extensive use when the ritual permits their use. The intensity of illumination in the chancel should be about twice that in the auditorium proper. Dimmers may be employed effectively for the auditorium lighting and at least two intensities of illumination should be available by means of switches.

Many other details of lighting are found in churches such as the illumination of the organ-keyboard, the choir, bulletin-boards, clocks and even electric signs. The beauty of the color of stained glass windows, only visible to the audience by light transmitted inward, may be enjoyed at night by flood-lighting them. A number of windows have been flood-lighted by means of artificial-daylight lamps and the contrast with the yellowish interior light is quite pleasing.

Theatres.—Many of the problems encountered in auditoriums and churches are found in theatres but in the latter case a touch of the spectacular and many novel effects are appropriate. Stronger color-effects are permissible than in other auditoriums and more spectacular dimming arrangements may be employed. A common annoyance is that of the bright orchestra-lamps or even the highly illuminated music-racks when the auditorium is dark. If chandeliers are used, tinted lamps appropriate to the decorative scheme may be employed and the psychological effect of colored light may be utilized. For example, during the hot summer months a cold blue-green tint is quite effective in suggesting coolness. Emergency and exit-lights are usually demanded by law.

The moving-picture theatre presents some additional problems owing to the continued darkness of the auditorium and to

the problems of projection. In entering from the street it is advantageous to the comfort of the patron to have the intensity of illumination decrease in steps to the darkness of the auditorium. Care should be taken to have the orchestra-lamps and music-racks screened from the audience and if the projection lantern is sufficiently powerful a low illumination in the auditorium is desirable from standpoints of safety and of eye-comfort. The picture-screen is often too bright in contrast with that of the surroundings for comfortable viewing. The flicker on the screen varies approximately with the logarithm of the brightness of the screen so that it appears well to reduce the screen-brightness as far as compatible with satisfactory pictures. Of course the perfection of the projection apparatus is a factor in the production of annoying flicker. The reflecting characteristic of the surface of the screen should be appropriately chosen according to the dimensions of the theatre. For narrow rooms, the screen may be of an aluminized finish or of any finish which spreads the light less than a screen painted with flat white. A screen approaching a perfectly diffusing surface is best for a wide theatre. In consideration of the comfort of the audience the auditorium lighting should be controlled by means of dimmers so that the intensity may be gradually decreased or increased respectively before and after the picture is presented. The screen may be illuminated with low intensities of colored light with excellent results if these tints are properly related to the picture. Usually fairly saturated colors are best because they are extremely diluted by mixture with the projected light. The environment of the screen provides opportunities for beautiful lighting effects.

CHAPTER XIX

INDUSTRIAL LIGHTING

When industrial lighting is considered from the broad aspect of vision, the lighting specialist is confronted with many diverse problems. In various other classes of interior lighting the problems are not merely confined to the realization of a given intensity of illumination upon a certain plane but involve the esthetic and psychological aspects. In industrial lighting the function of the lighting expert is not merely to provide a given intensity upon a certain horizontal plane but to illuminate the work properly without glare, to insure the safety of the workman by means of proper lighting and to protect his eyesight by means of various protective glasses and other devices. Thus it is seen that the problems of industrial lighting are largely scientific and engineering.

The intensity of illumination depends upon the nature of the work or activity and inasmuch as no other method of determining the proper intensity is available, the intensities are established by actual practice. Apparently there is no reason why much higher intensities of artificial light than are commonly used should not be satisfactory from the standpoint of vision and, although no positive proof is available, there is a possibility that much of the complaint against artificial lighting may be due to insufficient intensities or quantities of light. It should be remembered that under average daylight conditions the illumination intensities are much greater than commonly encountered under artificial lighting and that the eye functions quite differently at low intensities than at high intensities. Although the changes in these functions begin to be quite noticeable in general at brightnesses corresponding to that of a white surface under an illumination of a tenth of a foot-candle or less, this brightness corresponds to that of surfaces of low reflection-factors under an illumination of a foot-candle or more. In

other words, the visual functions are dependent upon brightness and it is possible under ordinary factory conditions of lighting and surroundings that ofttimes the eyes are expected to work on "high" when they are really in "low." This is an aspect of vision which has not been given much attention in respect to lighting and in the absence of more definite data it is a safe procedure to increase the intensities of illumination provided the light-sources are properly shaded and other precautions are taken.

The engineering aspects of industrial lighting have been subjected to much study during recent years and the lighting specialist is usually equipped with data, experience, and precedents which insure an excellent design wherever he has the opportunity to apply his knowledge. A few of the aspects which have been studied will be noted briefly.

Proper lighting has been shown to increase production. In a canvass made among a large number of industrial plants in which the lighting had been modernized, a considerable percentage reported increased production. Many reported that their operatives were better satisfied and in general the results were such as to increase production and to decrease spoilage either directly or indirectly.

It has been shown that inadequate illumination is directly responsible for many industrial accidents and that proper artificial lighting is a preventative measure. Statistics reveal the fact that the percentage of industrial accidents are more numerous during the winter months when daylight is often inadequate. Artificial lighting is an obvious remedy. Recently protective lighting has become recognized as a desirable feature of industrial lighting and as a consequence various methods of exterior lighting have been devised as an aid to watchmen. Flood-lighting projectors are playing an important part in such systems.

The system of illumination to be employed in a factory depends upon the particular conditions but general direct-lighting is strongly advocated. Such a system of illumination is not essentially more expensive to install and to operate than a haphazard system of localized lighting. In fact, records show that

adequate general lighting is sometimes obtained at a lower cost than unsatisfactory lighting, with the resultant increased production and less spoilage as good measure. Local units which may be shifted by the workmen to suit their desires are likely to be badly placed so that glare results; time is wasted in making these changes; and the lamps and accessories are likely to become soiled by handling them which reduces the effectiveness of the light-flux which is generated. If a localized-lighting system is subjected to a proper maintenance it is likely that in most cases this would be found to be a greater item of expense than that attending a proper maintenance of a general-lighting system.

There is a period of the day when daylight is waning and is being reinforced by artificial light which is generally unsatisfactory. There may be several reasons for this but the question has not been answered completely. In the design of a factory the machinery is either laid out and the building is erected about it or *vice versa*. In either case there is no doubt that the natural lighting is more or less considered in connection with the designs and layouts. Besides this the workman naturally adjusts his position somewhat to daylighting conditions and as a consequence when artificial light is added there is a conflict of shadows due to the generally different directions of natural and artificial light. This disturbance naturally lasts until artificial lighting has conquered the daylighting and the workman has become adapted to it. In so far as it is practicable, the artificial lighting should simulate daylight in distribution and hence in shadow-effects.

Even though this may be done there is usually the disturbing influence of the different colors of the two illuminants. The physiological or psychological effect of this unsatisfactory color-difference is unknown but that it is annoying is the testimony of many observers. The difficulty is eliminated by using artificial daylight and such a procedure has been adopted in some offices and in industrial plants even where the discrimination of colors is not of great importance. Incidentally one of the most modern developments in industrial lighting has been the recent adoption of the use of artificial daylight in many

plants. It is surprising to many to learn how extensive is the factor of color-discrimination in the industries. This is not only involved in textile mills, color-factories, lithographing plants, etc., but also in a vast number of other industries such as brass works, ore refineries, wood-working factories, etc., as shown in Chapter XI.

Glare is the most generally annoying feature of lighting and it is not completely overcome even when the light-sources are properly shaded. Proper diffusion or reduction of the brightness of the apparent light-source is necessary in order to avoid the annoying reflections of light-sources of high brightness from polished metals and other glossy surfaces. Practically no modern light-sources can be viewed with comfort at close range or when directly in the normal visual field. If the light-sources are hung sufficiently high and, if too bright, they are properly shaded and equipped with diffusing media, this source of glare is eliminated. However, if the background is too dark there still may be present an annoying glare due to contrast. Ideal conditions of maximum brightness have been suggested in Chapter V but for factory lighting these may be impracticably low. The solution then is to hang the units high. This may be impracticable in many cases owing to obstructions such as belting, shafting, beams, etc., so that compromises must be made. In any case the lowest practicable brightness should be obtained by diffusing media if necessary and the units should be equipped with proper shades.

Some modern factories are so laid out and are so comparatively free from obstructions that the outlets for a general lighting system may be symmetrically and regularly spaced according to aisles, tables, machines, or bays and the lighting problems are practically solved on selecting the reflectors or lighting units which give the proper distribution of light for the spacing and hanging height and on computing the luminous output required from each unit. The refinements of lighting arise in those installations in which various machines or operations require special treatment. For example, in a machine shop where machines of various duties cannot be arranged in uniform rows or from the nature of the work the shadows fall from

different directions, each machine should be lighted more or less independently. A general lighting system may still be used but the outlets must be spaced according to the locations of the machines. This treatment might be called "localized-general" lighting. If the units are hung high they will usually supply adequate lighting on the less important parts of machines, upon aisles, etc. In such a case the study of direction of light and of the shadows is important.

In some special cases an additional local illumination may be required but when this is resorted to, the installation should be permanent and unalterable by the operators. The light-sources should be well shaded and the light should be properly directed to the important point. Examples where such local units are being used satisfactorily are on sewing machines, work-benches where fine work is done, at indicators on machines, etc.

The control of various circuits or of individual lighting units by means of switches is an important economic factor in industrial lighting. In the ideal method of control the circuits are as numerous as necessary in order to provide for the operation of only those lighting units which may be necessary at any particular time. Various schemes of control are in use depending upon the local conditions; however, a general principle is to control the units parallel to the windows. In such cases the units farthest from the windows may be lighted first because daylight fails at such points before it does nearer the windows. Adequate control is a desirable feature in all lighting systems.

The maintenance of lighting systems is perhaps the most neglected feature of lighting. After a satisfactory system has been installed it is economical to organize a definite procedure in inspecting, in cleaning the various reflecting and transmitting portions of the units, and in replacing burned-out lamps or broken mantles. It is even economical to replace lamps and mantles which are still in operation but which have so deteriorated as to have passed beyond the point of economical operation. The depreciation of lighting units as to output is an unavoidable feature of any lighting scheme and especially is this a vital factor in industrial lighting. The surfaces of light-

ing units which are depended upon to reflect and to transmit light should be as smooth as possible if they are exposed to the atmosphere which is laden with dust and vapor. Windows and other glass skylights are commonly washed to let the daylight in but this custom has not been so generally in vogue with artificial lighting units. It has been shown by many who have kept records that depreciation in the efficiency of a lighting unit is an ever-present and important factor in industrial lighting and that a systematic maintenance is a profitable remedy.

In order to obtain efficient and satisfactory lighting, the surroundings, especially the ceiling, should be finished in white or in a light tint in so far as is practicable. This increases the utilization efficiency of the installation and often reduces or eliminates glare by providing a background of a sufficient brightness to reduce the brightness-contrasts between the lighting units and the background. Such surfaces also provide a more cheerful interior and the specifications of their reflection-factors and colors are included in the province of the activities of the lighting specialist. Pleasing and restful surroundings, which also have a degree of artistic value, are obtained by using shades and tints of green. The ceiling may be white or a very light tint of green or yellow. The upper walls may be a light shade of an unsaturated green and the lower walls and supporting columns may be of a moderate shade of green or olive. The same scheme may be used in respect to yellow with pleasing results. The upkeep of these surroundings is a matter of maintenance which should not be neglected.

As has already been stated the lighting problem has not been solved when a certain intensity of illumination has been provided at the work-points or work-planes. Proper lighting finally includes proper seeing and therefore all classes of work should be studied in detail. For example, we distinguish objects by discriminating differences in light, shade, and color. After a proper quality of light has been selected it should be distributed so that the objects are properly modelled by light and shade. Highly directed light may be necessary in some cases in order to distinguish small metallic objects by their high-

lights or to examine the polish of surfaces. In other cases highly diffused light from apparent sources of low brightness is best from the standpoint of the lack of shadows and of glare due to reflected images.

Furthermore, the background is an important factor in providing contrasts in brightness for viewing small objects. Often operators are seen doing fine work which makes the severest demand upon the ability of the eye to discriminate fine detail, under conditions which subject their eyes to strain owing to an accidental background consisting of an array of miscellaneous objects. For fine work a background should be provided which is of uniform brightness and of a suitable color. If the fine details are best seen as dark objects against a light background the latter should be provided. If they are seen more easily as bright objects, a dark background should be specified. It should be noted that the brightness of a background is co-dependent upon its reflection-factor and upon the intensity of illumination. The degree of contrast may be best determined by experiment although judgment is a valuable asset. Experiments on the color and brightness of backgrounds have been performed but owing to the variety of conditions encountered no general specifications can be offered. In the case of a certain operation gray, green, or buff backgrounds were found to be desired depending somewhat upon the operator. Severe headaches due to eyestrain were entirely eliminated in this case by supplying uniform backgrounds against which the work was viewed. This point is of considerable importance in the industries but the consideration of background has been much neglected.

In many industrial processes the eyes are subjected to the dangers of flying particles, to excessive heat, to high brightnesses, or to excessive and harmful ultra-violet rays. Safety glasses should be specified for safeguarding the eyes under such conditions. Protection from flying particles may be secured by using thick clear lenses mounted in approved holders. Clear glass lenses serve materially to protect the eyes from excessive heat which might burn the delicate membranes of the eye. It has not been proved that infra-red rays are harmful

to vision but it is a safety measure in certain processes to specify the use of glasses which are of low transmission-factor for these rays. Ordinary "smoke" glasses of various "shades" or transmission-factors are available for reducing the brightness of the retinal image to a safe value. The author has worked out a series of combinations of different shades of "smoke" glass with a glass which absorbs harmful ultra-violet rays for various industrial processes on the basis of the brightnesses and intensities of ultra-violet energy involved. If there were a rigid standard of shades of smoke glass such a series would be of extreme value to the industrial manager, to the lighting specialist and to others. This question cannot be discussed in detail here but there are several discussions of value to be found elsewhere.[1] The chief precaution is not to judge the protective value of a glass for invisible energy such as ultra-violet and infra-red rays by a mere visual inspection.

The intensities of illumination to be specified in the industries depends upon the character of the work and can be determined only from experience. For reasons already discussed it appears to be a safety measure to increase the intensities of illumination as far as is compatible with economy, to shade bare light-sources from the eyes, and to apply diffusing media in order to reduce the brightness and brightness-contrasts. The practice in industrial lighting at present is discussed further in Chapter XXII.

Reasonable uniformity of illumination over general work-planes is desirable from the standpoint of eye-comfort, safety and production. In this respect daylight is generally inferior to the best possibilities of artificial lighting except in those factories where adequate skylight-area is available. But this deficiency of daylighting is somewhat compensated in many places by the quantity of light-flux available and by its diffusion. Refractive and diffusing glasses may be used to advantage in directing or scattering natural light into the remote places and

[1] M. Luckiesh: *Trans.* I. E. S., **9**, 472, 1914: *Electrical World*, **62**, 844, 1913, and **66**, 576, 1915. Verhoeff and Bell: *Proc.* Amer. Acad. of Arts and Sciences, **51**, 629, 1916. Coblentz and Emerson, *Tech. Paper* **93**, Bull. Bur. Stds., 1917.

in eliminating the glare from the sun and the sky and the localized high intensities of direct sunlight.

In the foregoing it has been the aim to present the chief principles and advantages of proper lighting. As in other chapters, the space has been devoted to a discussion of these principles which will always be the guides of the lighting specialist instead of giving space to engineering data and descriptions of specific cases whose value is only temporary. Everyone engaged or interested in lighting may obtain the current data on illuminants, illuminating devices, and layouts, from the bulletins and catalogues of manufacturers which are issued as new lighting equipment appears on the market. Throughout this book it has been the aim to stimulate the consideration of the broader view of lighting and to record ideas and suggestions which may aid in building the foundation of creative work in a field of wonderful opportunities.

CHAPTER XX

STAGE-LIGHTING

It is difficult for one who has studied the possibilities of light, shade, and color as a means of expression and as an accompaniment to the play, to suppress a critical attitude toward the crudity of lighting effects on the present stage, the lack of scientific knowledge in utilizing the latent possibilities of lighting, the crude realism demanded by the public and therefore by producers, and the lack of appreciation of the functions of the lighting and setting in relation to the play. The material desired in a discussion of the present subject is doubtless that which may aid the lighting specialist in providing the lighting to meet the demands of producers in general; therefore much of the discussion will be confined to criticisms and to descriptions of present stage-lighting. However, the greater artistic, expressive, and psychological possibilities of lighting will be touched upon as well with the hope of adding something to the efforts of the gallant, though small band of stage artists, who are striving to realize a harmony of lighting, setting, and drama in the so-called modern theatre. Little groups are found here and there undergoing sacrifices for a cause which bears fruit if it does no more than point out some of the incongruities in the lighting and in the setting of the present stage. The fault lies with the public, for producers cater to the public's taste; therefore the present stage will not be remodelled in lighting and in setting, faster than is warranted by the change in the appreciation of the public.

To those who have not glimpsed the methods employed "behind the scenes" in obtaining lighting effects it perhaps appears strange to learn that the present stage-lighting is crude and the results are more or less accidental when they recall some of the wonderful lighting-effects which they have witnessed. But these effects are obtained, as a rule, by trial instead of by

the direct course which results from an acquaintance with the art and science of color. Furthermore, little thought is apparently given to the emotional value of light, shade, and color. Demonstrations of lighting effects before the public convince one that any effect, well-manipulated and striking, appeals to the general public regardless of its deeper relation to the scene or action. For this reason lighting has great possibilities in commanding the attention of the public.

The lighting of a stage-setting may be divided into distribution and quality of light, and in order directly to produce the effect which is born in the imagination, a knowledge of the principles of control of light and of the mixture of colors (both of pigments and of illuminants) are necessary. These have been discussed briefly in this book and have been described in detail elsewhere. Numberless effects of distribution of light lie between the extremes of diffusion and directedness or concentration.[1] Actors may be silhouetted against a bright background or may be brightly illuminated against a dark ground. Between these extremes are found numberless expressions of light. The possibilities of color are likewise infinite in variety and the stage should be provided with elaborate apparatus for controlling these two aspects of lighting.

The chief equipments for a stage are rheostats, foot-lights, border-lights, side-lights, flood-lights, and spot-lights. Notwithstanding the fact that tremendous wattages are required in obtaining brilliant color-effects, light is ordinarily used very inefficiently on the stage. Proper reflectors are extremely advantageous in such places as the borders but their use is relatively rare. Crude troughs and even less efficient accessories are the more common, although well-designed troughs of parabolic cross-section meet some requirements very satisfactorily. In a few cases the principles of efficient and proper lighting have been introduced upon the stage by lighting specialists, an excellent example of such work in this country being that of Bassett Jones[2] who has developed several novel and efficient lighting accessories.

[1] M. Luckiesh: "Light and Shade," 1916.

[2] *Electrical World*, **66**, 1915: *Trans.* I. E. S., **11**, 1916.

It is unnecessary to discuss the equipment which is available for stage-lighting effects because complete descriptions may be obtained from catalogues. However, it should be noted that in this field the ingenious lighting specialist will find applications for an extensive knowledge of details of the control of light and of color. In amateur or temporary productions, novel expedients are especially applicable owing to the usual unavailability of standard equipment. In such cases even dimmers are not always essential because beautiful effects may be obtained by moving templates or louvers before an extended light-source. For example, suppose it is necessary to simulate a camp-fire. Even on the professional stage this is usually done by covering an incandescent lamp with a tinted fabric and piling about it the fire-wood. Thus the "fire" burns with steady unrealism, whereas a simple arrangement of a diffusing glass or paper over which a template is moved manually provides a striking and artistic effect. Colored lights may be mixed effectively in this manner or by means of louvers.

One of the severest criticisms of stage-lighting from an artistic standpoint may be directed against the use of foot-lights for obtaining the dominant light. A dominant light directed upward from below the horizontal produces unnatural and even grotesque modelling of the actors' features and is incongruous with other real and painted effects of light and shade. Owing to present construction it is quite impossible to obtain a dominant light from above for the proper lighting of the front of the stage but worthy attempts have been made to do so by constructing a hood extending outward into the auditorium from the upper part of the proscenium arch. Other attempts have been made to obtain the desired directed light from the "front of the house" but such lighting usually leads to "flat" effects. Nevertheless, there is more experimental work to be done and it seems that this is one of the many fields where the architect and the lighting specialist may coöperate with the possibility of solving a difficult problem. However, even though a method may be devised for obtaining dominant light from above the horizontal, the foot-lights must be retained, for they would be invaluable in contributing those "fogs" of dif-

fused light in conjunction with border-lights and side-lights, which are necessary for illuminating the shadows.

Incidentally, such "fogs" of light, if colored and of sufficient intensity, provide a means for obtaining extremely striking and appropriate effects. For example, if an object or stage-setting be flooded with a high intensity of red light and a highly directed white light be superposed, the shadows will remain a deep shade of red and the high-lights will apparently be white. By the use of various colors of diffused light or even of various beams of light of different colors directed from various points, striking effects may be obtained. For example, imagine blue and yellow lights directed from different points toward the rear of the stage. Where both these colored illuminants mix in the proper proportions a synthetic white light results. Thus the high-lights on the folds of a garment would be illuminated by white light and the shadows would receive either blue or yellow light or various mixtures. Such effects are very beautiful and if, for example, dancers are moving about the mobility of the color-effects is very enlivening to the picture. These effects represent a step further in painting with light and no field offers greater opportunities for such applications than stage-lighting.

A number of types of equipment are available for foot-lights but the trough reflector is a basic principle of nearly all of these. However, it appears that a more elaborate switching control of the "white" foot-lights would be desirable in order to obtain a degree of directedness laterally, or at least an asymmetry of lighting which is the basis of many artistic effects. The modern high-efficiency tungsten lamps should be used more in foot-lighting equipment, but one disadvantage is the high temperature of the bulbs which rapidly deteriorates the superficial coloring which is commonly used. Colored glass filters could be used to advantage but owing to the wide variety in the colored lights demanded this is not always practicable owing to the usual limitations of the two or three circuits provided.

Owing to the apparent advantages of a permanent foot-light equipment it appears that a determined effort should be made to provide four circuits, namely, for clear lamps, and for red,

green and blue illuminants. By using modern tungsten (Mazda C) lamps the required intensities of illumination could be obtained from the fewer number of outlets which would be available owing to the limitations of space. By mixing these four illuminants by means of dimmers any intensity of any desired tint could be obtained and the installation could be permanent by using colored glass filters in the form of caps or plates. It is hoped that colored bulbs of sufficiently pure and correct colors will be available in the near future for these will greatly reduce the difficulties in securing permanent equipment and in realizing the best effects possible. The usual equipment provides white, blue, and red illuminants but the colored lights obtainable from these are much less limited than from the preceding four illuminants. If only three circuits are available a blue-green and an orange-red may be used with white if the aim is to obtain the greatest variety in color from three circuits.

Quite the same discussion applies to permanent border-lights and side-lights. Apparently the advantages of such a system have not been generally recognized but inasmuch as there are no insurmountable obstacles at present it appears that there should be a tendency toward the adoption of such a system which is the scientific solution of stage-lighting designed to meet a vast variety of requirements. Of course, the extensive use of yellow or amber light casts some doubt upon the desirability of obtaining this color inefficiently by mixing red and green lights instead of obtaining it directly, but the foregoing discussion is based upon the premise that permanency and flexibility are more important factors in stage-lighting equipment than efficiency of light-production.

The color-wheel, which consists of a number of sectors of colored glass or gelatines, and various movable color-screens have many uses in stage-effects and may be used advantageously in other fields. Miniature lamps, swinging or blinking, have their applications. Apparatus is available for simulating lightning which has often been done by bringing carbon and iron electrodes into contact. Gauze screens play many parts on the stage for producing various illusions but their use in-

volves lighting almost entirely. Projection apparatus and slides contribute much toward the success of some of the most scenic productions and even the rainbow as produced by a glass prism has been used. The many lighting effects employed on the stage are too numerous to embody in this discussion but they are always produced by the application of a few simple principles of the control of the distribution and color of light. In many ways the new incandescent lamps are likely to revolutionize stage-lighting because of their ease of control, of their application to projection apparatus, and of their high luminous intensities. Alternating-current arcs are often annoying owing to their "singing" and direct-current arcs require constant attention. If reflecting surfaces are used the mirror is most suitable to the control of light, but such diffusing media as the aluminized surface are best for diffused lighting. Many simple expedients may be resorted to in order to prolong the life of the colored gelatines which are so extensively used for color-effects in stage-lighting. These in general involve the basic principle of having most of the undesired radiant energy absorbed by other media which are uninfluenced by light and to provide a free circulation of air between these media and the colored gelatines as shown in Fig. 8.

For outdoor productions the so-called flood-lighting units are extensively used. Often it is desirable to eliminate the cone of direct light in order to confine the light to the useful beam and to prevent the annoyance of the stray light which is not confined to the beam. This is effectively done by using cylinders of blackened metal concentric with the axis of the beam or unit. Such screens may be fastened very easily to any projector unit. In outdoor productions ordinary reflectors, having enamelled or aluminized surfaces, are satisfactory for foot-lights, for flood-lamps of short range, and for various other uses on or near the stage. Metal guides may be fastened to these metal reflectors and in these the color-slides may be fixed or moved.

Inasmuch as the science and art of lighting in general has not invaded the stage sufficiently even to introduce efficient lighting accessories such as well-designed reflectors and pure color-

ing media, it requires temerity to suggest that the stage artist familiarize himself with the science of color-mixture and with the spectral characteristics of the colored media which he uses or which are available. Nevertheless, he will ever work blindly until he gains such knowledge. He should study his coloring materials with a spectroscope or should have them analyzed by means of a spectrophotometer. The data yielded by such analyses provide a working knowledge for the application of these materials. In a similar manner he should realize that the color of an object is influenced by the spectral character of the illuminant. In such matters the eye alone is not capable of supplying the analytical data required, for it is a synthetic apparatus in respect to color. He should be familiar with the laws of color-mixture which are quite different for pigments than for illuminants. In the case of pigments the resultant color of a mixture is due to subtraction or absorption of various spectral components and the resultant color is that which is reflected or transmitted in common by the colored media of the mixture. The superposition of colored glasses or gelatines is governed by the same laws of color-mixture as the mixing of pigments. Thus, yellow and blue glasses superposed result in a green color and the result is quite the same with pigments. The primaries of this method of color-mixture are purple, yellow, and blue-green.

In the mixture of colored illuminants the resultant color is that due to an addition of the components. In the case of adding blue and yellow illuminants the resultant color will be white if the proper balance is obtained. The primaries of the additive method of color-mixture are red, green, and blue and, by varying the proportions of these components in a mixture, a great variety of hues may be obtained even with impure or unsaturated colored illuminants available in practice. This aspect of the science of stage-lighting should not be ignored by the stage artist who hopes to avail himself of the dormant possibilities of lighting. An extensive treatment of the science and art of color would be out of place here but such will be found elsewhere.

The stage artist will find a delightful field for applying a

knowledge of scientific and artistic lighting to such miniature stages as the shadowgraph, the marionette theatre, and various other small stages. Some of these present problems as difficult to solve as those encountered on the normal stage.

There are many incongruities to be found in stage-effects not only in respect to lighting but also to scenery and setting. Many of these are due to the attempts toward realism. For example, the painted perspective cannot in general coincide with the real perspective. Gauze, sky-domes, and various lighting effects amid plain surroundings go farther toward the realization of distance and atmosphere than attempts in realism by means of painted perspective. Likewise, the painted shadows, in general, are not in harmony with the real shadows. It is safer in seeking for harmony of play, of setting, and of lighting to abandon the crude realism for the simplest surroundings and the art of the stage will be advanced by applying thought and research to new expedients and to the expressive possibilities of lighting. The latter are found in light, shade, and color effects directed artistically and scientifically with the psychological aspect of the action and mood of the play foremost in the mind of the stage artist. The stage is a most excellent place to paint with light.

One of the superior features of light as an expressive medium is the ease with which mobile effects may be obtained. A painting on canvas is fixed and it can never be more than a representation of a momentary thought or scene. The artist may suggest motion or action but the imagination of the observer must supply the remainder. Technically a painting is a cross-sectional view of the flow of thought or action; however, the mobility of lighting effects greatly extend the expressiveness of a scene. The fixed painting is analogous to a chord in music and the successions of effects due to mobile lighting comprise a symphony of lighting. In this direction the stage artist may explore a vast unknown from which we may confidently expect some novel, artistic, and psychological developments. Mobile lighting is not new in our experience for the thoughtful observer will find it everywhere in Nature. In a sense we experience some of the pleasure of mobile color as our eyes rove over a rug or painting or other colored object. However, the language

of color is not well enough known to justify some of the brazen attempts which have been made in mobile color. It is discouraging to note these feeble and superficial attempts which have been made to relate mobile color and music on the basis of similarities in technique and in other respects. However, color is appealing to mankind and is influential in various ways on the human organism so that mobile color may take its proper place in company with music, dancing, painting, and other modes of appeal. This aspect is discussed further in Chapter XXIV.

The stage as a whole is a mobile picture and for this picture all the ingenuity of the stage artist should be drawn upon. The whole is an illusion or at least it is the aim that it should be. The preceding discussion has been confined chiefly to lighting but scenery and furnishings are closely allied to lighting. The scenery should be painted and the actors costumed with a definite idea of the lighting effects in mind because the changes in the color of the light are accompanied by changes in the colors of the dyes or pigments in the setting. Sometimes these latter changes are unsatisfactory. It is beyond the scope of this book to dwell upon the many details of color-science which may be applied here such as dyes having the property of fluorescence or other characteristics but there are many such applications to the infinite variety of problems which arise on the stage. However, in closing it may be of interest to mention the possibilities of obtaining disappearing effects and complete changes in scenery as originated by the author a number of years ago. By choosing coloring media of certain desirable physical characteristics and by properly employing them in painting certain parts of a scene, complete changes in the latter may be accomplished if the spectral characters of the illuminants are properly related to those of the pigments. In other words two scenes may be painted on the same canvas and one will disappear under one illuminant and the other will be brought out in sharp contrast. Under the other illuminant the reverse is true. More than two complete changes are possible but great difficulties arise when more than two are attempted. For a description of this the reader should refer to another source.[1]

[1] M. Luckiesh: "Color and Its Applications," 1915, p. 272.

CHAPTER XXI

SPECTACULAR LIGHTING

There are many opportunities for employing light for the purpose of obtaining spectacular effects and many other effects which may not be classed as spectacular but whose primary purpose is to attract attention. These problems may be best viewed from the standpoint of light, shade, and color as is the case with nearly all lighting problems. Accessories of many designs are available for obtaining a vast variety of distributions of light but the color effects are difficult to obtain at present owing to the inefficiency in the production of colored light and to the scarcity of color-screens which are permanent and easily adaptable. There is a need for such color-screens and colored lamps which, as it grows more urgent, will doubtless be met by manufacturers, but in the meantime the pioneer in certain fields of lighting must strive under the handicap of devising various accessories. For this reason the development of certain aspects of lighting, which may best be included in this chapter, is somewhat deterred. In the case of a problem of large magnitude such as the lighting of the Panama-Pacific Exposition it is practicable to develop the various accessories which are necessary in order to tap the resources of lighting possibilities, but the lighting specialist does not always feel justified in doing this in the cases of lesser magnitude. However, many opportunities pass by daily which should be grasped by those interested in the development of lighting-practice.

Perhaps the most extensive field of lighting which may be classed as spectacular is the lighting of exteriors of buildings, monuments, and other architectural works. It is often a primary aim in such lighting to attract attention but many cases may be justified on a sounder basis. For example, many persons seldom have an opportunity for viewing some of the architectural works of art such as monuments and buildings except at night and the expense of flood-lighting them may be justi-

fied on the same basis as their existence is justified, namely, to beautify the world in which we live. Of course, there are other aspects of flood-lighting which are purely utilitarian.

On looking backward only a few years we see a sudden departure from the old scheme of outline lighting by means of incandescent lamps to the new method of flooding the object with light from projectors or concealed units. In the former method the object was not made visible in general, for the effect seen was that of a pattern of light-sources. This method has been largely superseded by the more practicable and, in general, more satisfactory method of flood-lighting; however, there are still many applications for outline lighting, especially when the patterns of light-sources are combined in a decorative manner with signs studded with lamps or with other decorative effects such as festoons of lamps. The wiring difficulties are generally much greater than those attending the modern flood-lighting installation.

The next step in the evolution of the lighting of exteriors was to conceal the light-sources along cornices and behind other projecting parts. The effect of such "concealed" lighting is often very satisfactory for, compared with outline lighting by means of exposed light-sources, it is often more pleasing because at least a portion of the architectural pattern is visible. The next step was, logically, to flood the entire exterior with light or at least to illuminate prominent portions of it such as a dome or tower. As a consequence, during the past few years flood-lighting has revealed the beauties of such works of art as the Statue of Liberty, the Woolworth Tower, the National Capitol building, and the entire exterior of the Panama-Pacific Exposition. In the last case and in others of minor importance, color-effects have played an important part.

But flood-lighting has not been confined to the lighting of architectural works for it has been applied to pageantry, to the lighting of stained glass windows, to entire grounds such as parks, and among the earliest successful attempts the Niagara Falls was flooded with light. Those who witnessed the lighting of this natural wonder will perhaps find it easy to justify the employment of flood-lighting purely as a source of pleasure.

As the cost of lighting decreases, it appears safe to conclude that the applications of flood-lighting will greatly increase.

The so-called searchlight has been a prominent factor in this field of lighting but with the recent developments in incandescent filament lamps the available units have been extended greatly. There are now available a large number of projector units varying in size and in distribution characteristic from a highly concentrated beam to one of considerable spread. When a small area is to be illuminated, or the distance from the unit to the object is large, the more concentrating units are generally the proper ones to use. However, if it is necessary to place the units close to the surface to be illuminated, a beam of greater spread is usually necessary. There should be no difficulty in choosing the proper units by considering the manufacturer's data in connection with the specific conditions of the problem.

There is an artistic aspect in most of the cases of flood-lighting which should be considered. Architecture has developed under daylight conditions in which the dominant light reaches the object from above the horizontal plane of the object. In fact, an angle of about 45 degrees has been a prominent factor in the evolution of architectural details. Besides this it should be remembered that a great deal of light reaches the shadows both from the sky and by reflection from surroundings. For these reasons the shadows in the daytime are projected in a general downward direction and are not relatively as low in brightness compared with the high-lights as under artificial lighting. Therefore, if it is the aim to preserve the effect which the architect has produced, the dominant light should be directed from a point considerably above the horizontal plane in which the objects are located. For example, if a monument is to be flood-lighted with the aim of reproducing the daylight effect of light and shade as far as practicable, the dominant light should be projected from a point sufficiently high so that the angle is from 30 to 45 degrees above the horizontal plane. However, owing to the scanty amount of diffused light which illuminates the shadows at night it is often better to compromise by directing the light more nearly horizontal than would be desired if this difficulty were not encountered.

Often it is impossible to flood the object with light except by projecting the light upward. In such cases, the daylight appearance is not obtained and in some cases the effect is grotesque. However, in many cases the effect as a whole is striking and attractive. This is especially true if there are no conspicuously projecting features or ornaments on the exterior but in general the effect is more satisfactory when the light reaches an object from a point above the horizontal plane of the object. The selection and location of the units are largely engineering problems although the artistic aspect should be borne in mind when considering their location.

One of the greatest advantages of the flood-lighting unit is that the distance from which a given area may be highly illuminated is greatly increased over that at which an ordinary reflector may be employed. The latter may be located close to a billboard, a stained window, or building exterior and the results are quite satisfactory. However, a concentrating projector may be placed several hundred feet from the top of a chimney, tower, or monument and, owing to the high flux-density of the beam, the object may be highly illuminated. For example, the top of the Washington Monument has been illuminated from a distance of hundreds of feet and the effect is very attractive and even mysterious. Signs painted on chimneys and towering spires are illuminated very satisfactorily in this manner. One of the prettiest effects is obtained from a projector located on top of a chimney which emits smoke or steam by projecting the light upward. Thus the smoke or steam is illuminated and owing to its changing pattern the effect is beautiful especially if a tinted color-screen is used. One disadvantage is that such illumination unduly advertises the undesirable smoking chimney, nevertheless the idea may be applied in many cases, especially in connection with a sign at the top of the chimney.

An example of this effect on a large scale is the scintillator originated by W. D'A. Ryan who employed a battery of powerful searchlights and jets of steam. These beams, which were arranged in a fan-like manner, illuminated the clouds of steam in a spectacular manner. When equipped with colored

screens the effect is very beautiful. On foggy nights such an effect is commonly witnessed when searchlights are in use. Ryan has employed artificial "clouds" on various occasions with excellent results.

The effects obtained by illuminating fountains are not far removed from those obtained with other mobile media such as steam and smoke. Illuminated fountains and cascades have been attractive and spectacular features of some of the large expositions and many interiors and exteriors have been beautified by using flashing colored lights for illuminating small fountains. Such installations are not difficult to make especially if planned in advance of the construction. If gelatine color-screens are employed it is essential to provide an easy means for renewing them. The selection of the colors is a matter of taste but it is usually more satisfactory to employ tints than the purer colors. A checkerboard color-screen made up of small and irregular-shaped pieces of colored media may be used to advantage. The mixing of the colors by refraction and reflection in the moving water adds a liveliness and variety which may be very attractive if done properly. In such effects rheostatic control is often a desirable feature. The units may be immersed in water-tight compartments or the light may be projected from above if desired.

The lighting of the Panama-Pacific Exposition was an excellent example of the use of various modern illuminants and many special light-sources and color-screens in a spectacular effect of large magnitude. In such effects the flicker of electric arcs and gas lamps is often attractive. At this exposition a system of masked flood and relief lighting was generally employed. The intensities of illumination ranged from 0.1 to 3 foot-candles on roadways and building facades and from 5 to 15 foot-candles on certain points of interest such as towers, flags, and sculptural groups. The use of "jewels" on the Tower of Jewels is well known and the myriads of scintillating reflected lights viewed against the dark sky was a fitting climax of spectacular and gorgeous beauty. No brief discussion can do justice to the magnificent spectacle of lighting at this exposition, so the reader is referred to descriptions of the installations and effects ob-

tained as presented by W. D'A. Ryan who conceived and executed the plans for this greatest achievement in spectacular lighting.

There are many opportunities for spectacular and attractive lighting on a small scale in which the possibilities of striking distributions of light and color-effects may be employed. It is strange that advantage of these possibilities has not been grasped more fully in advertising. For example, a simple scenic sign in color may be made a great deal more striking by the use of colored illuminants. Mobile color-effects may be produced readily by varying the color of the light in a desired sequence by means of motor-driven rheostats, flashers, or templates. In such a case, dawn, noon, sunset, and moonlight effects may be obtained in a proper sequence in the course of a few minutes with the result that the sign is of much greater value as an advertising medium. It is well known that such variations in intensity and in color draw the attention of many more persons than if the intensity and color of the light were constant. The color-effects may be obtained from units supported in front or the sign may be recessed in a manner similar to a shallow stage. In the latter case the light-sources may be installed behind opaque screens such as are employed on the stage.

Mobile color-effects may be obtained in a variety of ways. One of the most complete and effective schemes is to employ red, green, and blue lamps whose intensities are controlled by means of rheostats. An apparatus for such a purpose may be made as indicated in Fig. 40. A series of contacts are placed on the circumference of a cylinder as shown and these are points on a continuous resistor of the proper current-carrying capacity and resistance depending upon the wattage of lamps to be used. Two arms, *a*, attached rigidly together, are connected to one side of the line and are rotated by means of a small motor. The red, green, and blue lamps are connected as shown and by this means the spectral colors may be produced in their proper order with purple spanning the gap between blue and red. The sequence is as follows: red, orange, yellow, green, blue-green, blue, blue-purple, purple, red-purple, etc. The modifications

which must be made in this apparatus for producing other desired sequences of colors should be obvious.

The same effect may be produced with water rheostats by

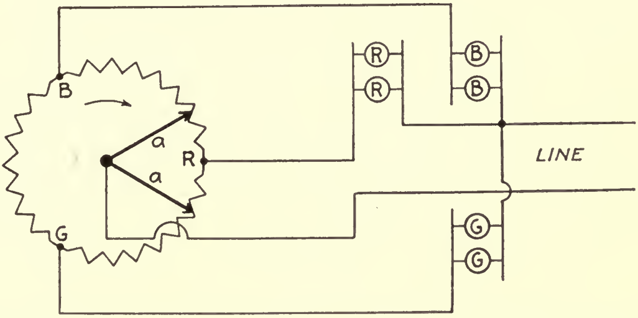

FIG. 40.—Apparatus for mixing red, green, and blue lights for mobile-color effects.

operating plungers by means of cams or eccentrics. Such a scheme is indicated in Fig. 41, where *V* is a vessel filled with salt water, *P* is a plate connected to one side of the line, *R* is a

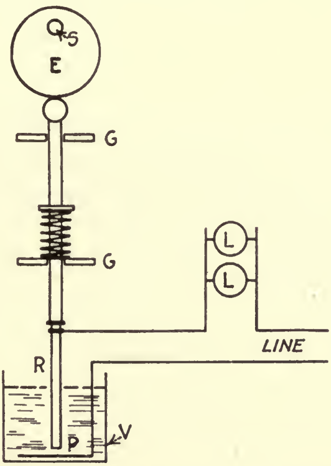

FIG. 41.—A simple rheostat which is adaptable to mixing colored lights by varying their intensities.

metal rod connected to the other side of the line, *L* are incandescent lamps, *G* are guides for the rod which is kept in contact with the eccentric *E* by means of a helical spring. Several

mechanisms of this sort may be operated from the same shaft S and by varying the design and angular position of the eccentrics or cams various effects may be produced. The various dimensions and other features may be determined readily by experiment for a particular case.

As mentioned in another chapter, templates, color-wheels, color-mixers, etc., provide other means for obtaining mobile color-effects. Many places are found in lighting for such apparatus even on a small scale. Among these are signs, displays, show-windows, fountains, the stage, etc. A vast amount of ingenuity may be expended upon the electric sign in order to develop all of the possibilities of this field of spectacular lighting.

Spectacular effects are merely the result of applying well-known facts of optics and the possibilities are so extensive and depend so much upon the particular case that little more can be done in a brief chapter than to describe a few cases and to make a few suggestions. Many of the simple facts of light, shade and color have been discussed in preceding chapters and have been treated extensively elsewhere so that those who meet such problems should be able to solve them. The more important fact is that lighting specialists are overlooking opportunities daily for tapping the potentiality of lighting. On every hand such opportunities are to be found but it is necessary to exercise ingenuity and imagination in utilizing light in this manner. There is some apparatus available but usually it is necessary to devise it for a specific case. For this reason the subject cannot be treated briefly and to do it full justice by discussing the many details elaborately is quite beyond the scope of this small volume.

CHAPTER XXII

COMPUTATIONS AND DATA

The viewpoint expressed in this book is that lighting should be considered much more broadly than is usually done in aiming merely to provide a certain more or less empirical intensity of illumination on a horizontal "work-plane." For this reason considerable stress has been laid upon the distribution and color of light over the entire room which includes walls, ceiling, and the various objects as well as the floor. Furthermore, the problem of lighting should be considered as being closely allied or even synonymous to vision; therefore various planes and even the details of seeing should be reckoned with in most lighting problems. It is also necessary to distinguish between illumination and brightness—respectively, cause and effect—and it is thus seen that the color and reflection-factors of backgrounds and of the various elements of decorative schemes must be considered.

Few working rules are available which may be depended upon at the present time for designing lighting installations from this broader view which aims to do justice to the potentiality of light and, therefore, the lighting specialist must draw upon various sources of information and through imagination, experiment, and experience he should be able to utilize light in lighting effects in a manner similar to that of the painter whose media are pigments. A great amount of lighting may be done very well without resorting to computations. In fact much of the present practice is the result of experience and judgment in which computations are practically impossible or unnecessary. However, in many cases it is necessary to have a certain illumination intensity on the floor or on an imaginary plane somewhat above it. By choosing the proper lighting equipment the desired general effect may be obtained and by computation the required luminous output of each unit may be determined.

Uniformity of illumination is another factor which is often important. This is usually a matter of properly relating the spacing and mounting height of the lighting units which are chosen. For example, if direct-lighting units of broad or extensive distribution are chosen it is obvious that they may be hung higher from the "work-plane" or spaced farther apart than if concentrating or focusing units were selected. The relation between mounting-height and spacing-distance is purely geometrical and it is possible to establish relations for various general types of units which will yield satisfactory results in practice. A few data of this character are presented in the accompanying table in which mounting-height is the vertical distance between the horizontal plane under consideration and that of the units. In the case of indirect and so-called semi-indirect lighting, the mounting-height is the vertical distance between the "work-plane" and the ceiling, the latter being considered to be the light-source.

Relation Between Spacing and Mounting-height for Approximately Uniform Illumination on a Horizontal Plane

Equipment		$\frac{\text{Spacing-distance}}{\text{Mounting-height}}$
Prismatic, mirrored, or aluminized reflectors	Focusing	¾
	Intensive	1¼
	Extensive	2
Opal bowls		1⅔
Opal domes		1⅔
Enclosing glass units		1⅔
Semi-indirect units		1½
Indirect units		1½

For example, suppose a large office is to be provided with an approximately uniform intensity of illumination on the plane of the desk tops, 2.5 feet above the floor. Assume that the ceiling is 15 feet above the floor and that extensive prismatic reflectors appear to be the most desirable equipment for this case. It is well to hang units high; therefore 10 feet will be chosen as the mounting-height. The spacing will be found by multiplying the ratio 2, from a previous table, by the mounting-

height, 10. The result is 20 feet between units. In many offices of these dimensions either semi-indirect or indirect lighting is quite satisfactory. If such units are desired, the spacing will be found by multiplying the ratio 1.5 by 12.5. The result is approximately 19 feet between units.

The intensity of illumination which is acceptable for a certain activity or condition is largely a matter of opinion or of experience inasmuch as satisfactoriness must be the guiding factor in the absence of direct methods of determination. If any criticism may be directed at the intensities of artificial illumination which are found in practice at the present time they will generally be safely criticized as being too low. If the light-sources are properly diffused and if brightness-contrasts are not too high there appears to be no reason except that of economy for not employing intensities of illumination many times greater than those ordinarily encountered. The intensities of daylight are ordinarily much higher than those considered sufficiently great for artificial light. The daylight intensities range as high as 10,000 foot-candles outdoors on a clear day and it is not unusual to find intensities indoors of hundreds of foot-candles. However, we appear to be content with an illumination indoors of a few foot-candles of artificial light.

The eye is a wonderfully adaptable organ for it adjusts itself for ranges of intensity of illumination and of brightness represented by millions. That is, we are able to see well under daylight intensities outdoors of thousands of foot-candles and fairly well, when the eye is properly adapted, under intensities of thousandths of a foot-candle. In other words, the eye is capable of recording brightnesses extending over an enormous range in value. Perhaps no instrument constructed by man has a range of sensibility comparable with that of the eye; however, it appears reasonable not to depend too much upon this wonderful flexibility of the visual organs. The ability of the eye to distinguish minute details, brightness differences, hue differences, flicker, etc., is, in each case, a function of the illumination or brightness and in many cases appears to be directly proportional to the logarithm of the brightness.

For this reason, there is little difference in the sensibility of the eye to these factors over a wide range of illumination or brightness; however, at low illuminations or brightnesses the sensibility generally decreases rapidly. Although there is no definite brightness at which the eye begins to function differently, it may be safe to state that a general decrease in sensibility and change in the functions of the eye begins to be evident at brightnesses corresponding to that of a white surface under an illumination of 0.1 foot-candle. This corresponds to brightnesses of objects of lower reflection-factors under illuminations of higher intensities. In fact, from this view of the physiology of vision it appears reasonable to state that in order to be safe the intensities of artificial light should be generally raised so that nobody is obliged to work constantly under intensities of illumination less than a few foot-candles. This may appear to be a radical view but in the absence of more definite data it is at least a safe one and it will not be surprising if, eventually, it were proved that much of the criticism of artificial lighting is due to the low intensities employed.

A table is given of the intensities of illumination which are generally considered as acceptable practice at the present time for various activities. These values should be viewed in the light of the foregoing discussion and should be considered as being merely tentative values subject to change as our knowledge of this phase of lighting increases. In specifying intensities of illumination for various activities which are practised in the same room or in adjoining rooms the local conditions must be considered. For example, a rather low value of illumination is given for storage rooms; however, if operators are obliged often to leave a highly illuminated room to enter this storage place it would be better to supply a higher intensity for the latter space in order to avoid the discomfort and loss of time required in adapting the eyes to this extreme difference in the two levels of illumination. Consideration of such factors of vision results in proper lighting and distinguishes the lighting specialist from those who merely follow empirical rules which cannot possibly cover the varying condition found in practice.

The computation of illumination intensity is easy in simple

cases but in the complex cases of practice where light arrives at a given point from many light-sources and by reflection from many objects it is quite impossible to compute the intensity of illumination at the given point. For this purpose various factors, such as coefficients of utilization for various general conditions, are experimentally determined and these are used in computations. Before discussing these it appears of interest to treat the simple case. In Fig. 42, S is a small surface perpendicular to the line joining its center with the light-source. If the luminous intensity or candlepower of the light-source is I in the direction of a given surface, and the distance from the source to the surface S is equal to d in feet the illumination E of the surface in foot-candles is represented by

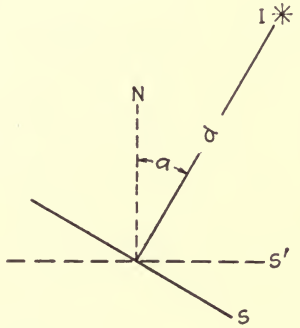

FIG. 42.—Illustrating laws of illumination.

$$E = \frac{I}{d^2}$$

This is the "inverse square" law so common in physics and is used in photometry very considerably. In general the surface is not normal or perpendicular to the line joining it and the light-source. Assume it to be in the position S' and the angle between the normal to the surface N and the direction toward the light-source to be a; then the illumination in foot-candles or flux-density on the surface S' is represented by

$$E = \frac{I \cos a}{d^2}$$

In other words, as the angle of incidence a increases the flux-density on the surface decreases, the latter being a maximum where a equals zero and a minimum (zero) where a equals 90 degrees.

The foregoing also represents the definition of a foot-candle which is the illumination on S when the distance to the source is 1 foot and the luminous intensity of the source in the direc-

tion of *S* is equal to 1 candle. The latter unit is an arbitrary standard adopted and maintained by the national laboratories of several countries including the United States.

Inasmuch as the luminous intensity of light-sources varies in general in different directions, the mean horizontal candlepower has been extensively used as a means of comparing the luminous intensities of light-sources. In some cases, such as in street lighting, the light emitted below the horizontal has been considered the useful light and therefore the mean lower hemispherical candlepower has been used to some extent for comparing light-sources and lighting units. Another step was taken in averaging the candlepower of a lamp in all directions and this is called the mean spherical candlepower of the lamp. Although of these various measurements of luminous intensity or candlepower the last is the most serviceable none of these gives an indication of the total quantity of light emitted by a source. Candlepower in a given direction corresponds to a measurement of the depth of a pond of water at a certain point but gives no indication of the quantity of water in the pond.

Thus it is seen that a unit is necessary in terms of which the quantity of light emitted by a source may be measured. For this purpose the lumen has been adopted as the unit of luminous flux and it is equal to the flux emitted in a unit solid-angle (a steradian) by a point-source of 1 candlepower. There are 4π unit solid-angles radiating from a point in space so that a point-source having a luminous intensity of 1 candle in all directions or a mean spherical candlepower of 1 candle, emits 4π lumens. The luminous output of any source, expressed in lumens, is equal to the mean spherical candlepower multiplied by 4π which is approximately equal to 12.57.

This may be made more clear by referring to Fig. 43 in which a source having a luminous intensity of 1 candle in all directions is assumed. Suppose an imaginary sphere having a radius of 1 foot envelops the source which is at the center. If this sphere is perfectly black inside, only light coming directly from the source will escape from any opening such as *OO*. The quantity of light which escapes will vary directly as the area of the opening, however a point at a certain place along the line *H* will have a

constant illumination regardless of the size of the opening assuming the source to be confined to a relatively small area. This shows that the illumination at a given point depends upon the candlepower in its direction but of course the distance to this certain point is also a factor as already shown.

If the quantity of light (luminous flux) which escapes from this blackened sphere depends upon the area of the opening it is obvious that we have a means of establishing a unit of luminous flux. If the area of the opening is taken as 1 square

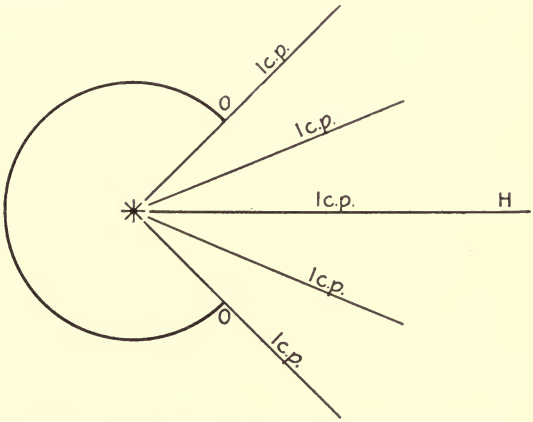

FIG. 43.—Illustrating luminous output (lumens) and its relation to luminous intensity (candles).

foot and the radius of the sphere is equal to 1 foot, 1 lumen of flux will escape. This solid-angle will remain the same for any sphere if the proportions are kept the same and thus serves as a unit solid-angle. There are 4π or 12.57 square feet on the surface of this sphere of 1 foot radius and therefore there are 4π solid-angles surrounding the center. Furthermore, there are then 4π lumens emitted by this point-source of 1 mean spherical candlepower as has been stated above.

It is obvious if the point source has a luminous intensity of 5 candles in all directions, that there will be five times as much light emitted by a given area of an imaginary spherical envelope or by a given solid-angle. It is easy to see from the foregoing that the intensity of illumination on the sphere in Fig. 43 is 1 foot-candle, hence the intensity of illumination of

a surface in foot-candles is numerically equal to the lumens incident upon the surface.

Recently there has been a general acceptance of the lumen and the luminous output of lamps and of lighting units is being expressed in lumens. In fact, the introduction of the lumen has resulted in a more rational method of dealing with luminous flux. In computations it is essential to know that for every foot-candle of intensity per square foot of a given plane, 1 effective lumen is required. However, it is impossible to compute the amount of light contributed to a certain point by reflections from various surfaces in a room so that computations must be based upon the general results of experiment. For this purpose the coefficient of utilization is used. This is the ratio of the lumens which reach the horizontal "work-plane" 30 inches above the floor to the total lumens emitted by the primary light-sources. Obviously the coefficient of utilization will depend upon the nature of the lighting unit and upon the reflection-factors of walls and ceiling. In the accompanying table such data are presented for three types of lighting systems, and for three sizes of rooms, for two different combinations of reflection-factors of walls and ceiling.

Approximate Coefficients of Utilization[1]

(Modern Lighting Equipment with no Allowance for Depreciation)

	Ceiling—nearly white; walls—high reflection-factor	Ceiling—nearly white; walls—medium reflection factor
Small Rooms (Offices, corridors, etc.)	Per cent.	Per cent.
Direct lighting; dense glass	40	36
Semi-indirect lighting; dense glass	25	22
Indirect lighting; mirrored glass	23	20
Medium rooms (Classrooms, laboratories, etc.)		
Direct lighting; dense glass	48	45
Semi-indirect lighting; dense glass	32	29
Indirect lighting; mirrored glass	29	26
Large rooms (Auditoriums, assembly rooms, etc.)		
Direct lighting; dense glass	60	58
Semi-indirect lighting; dense glass	43	41
Indirect lighting; mirrored glass	40	38

[1] Determined by Engineering Department, National Lamp Works of General Electric Company.

Illumination Intensities Which are Acceptable at the Present Time

	Foot-candles
Churches, theatres, lodge rooms	1.5–3.0
Gymnasiums	1–5
Armories, public halls	2–4
Libraries	3–6
Schools: classrooms, study-rooms, libraries, laboratories	3–6
Show-windows (depending largely upon goods displayed and intensity of street illumination)	10–50
Accurate color-discrimination	10–50
Stores:	
Department, dry goods, clothing, furnishing, millinery, jewelry, etc.	5–10
Drug, florist, furniture, book, grocery, meat, etc.	3–6
Offices	4–7
Industries:	
Foundry, rough wood-working, pottery, baking	2–4
Fine wood-working, rough metal-working, laundries, canneries, paint, paper, textile, printing, forge	3–6
Fine metal-working, cabinet-making, jewelry, garment, shoe	5–10
Drafting, sewing	8–12
Storage, passageways	0.25–1.00
Stairways	0.5 –2.0
Packing and shipping	1–4
Building exteriors	3–15

It follows from the foregoing discussion that the lumens, L, to be emitted by the primary light-sources in a given room of floor-area A in order to supply an average intensity of illumination E in foot-candles on the horizontal work-plane, is found by means of the following relation,

$$L = \frac{AE}{U}$$

where U is the coefficient of utilization. Owing to accumulation of dust on the lamps and on the reflecting and diffusing surfaces of the lighting units and, owing to the decrease in the luminous output of lamps, an allowance should be made for depreciation. This allowance is so variable that no single value would be equitable for all cases; however, owing to the fact that the illumination intensity E is not a rigid requirement it appears safe to allow a depreciation of 20 per cent. of the initial value.

Assume that a room, 20 by 30 feet, is to be provided with an

intensity of illumination of 5 foot-candles on a horizontal work-plane and that an indirect lighting system is chosen as most suitable for the given case. The room may be considered of medium size and if the walls are of high reflection-factor and the ceiling is white, the coefficient of utilization is found in the preceding table to be 0.29. The total lumens required from the lamps are equal to

$$L = \frac{20 \times 30 \times 5}{0.29} = 10{,}300 \text{ (approx.)}$$

If 20 per cent. more lumens are allowed for depreciation, the total lumens required will be approximately 12,360. If the ceiling height is such that six units are required it is seen that about 2060 lumens must be generated in each lighting unit. The size of the individual lamps may be determined from the manufacturer's data and from other considerations.

Often the construction of the room and the decorative scheme determine the locations of outlets and, therefore, units must be selected which provide the desired uniformity and intensity of illumination under the conditions. In fact, it is seldom that an appropriate lighting installation will be determined by blindly following such computations as presented in the foregoing; however, some definite basis must be available for making preliminary computations. These data are intended for such a purpose.

In the past many computations were made on the basis of watts per square foot of floor-area and by weighting the various obvious factors such as the type of lighting unit, the size of the room and the reflection-factors of walls and ceiling. For installations of gas units a corresponding input-factor was used. However, it is seen that such a basis is not as satisfactory as the lumen basis because in the former case the luminous efficiency of the lamp must be considered. Now that manufacturers are rating lamps in lumens it is well to adopt the latter basis for computations.

In the case of a show-window such a basis as lumens per running foot of the window provides a means for determining the size of lamps required. In the case of tungsten lamps the

computations are generally made on the basis of watts per running foot because the general practice is now confined largely to certain types of lamps not differing greatly in wattage and in luminous efficiency. A simple rule[1] for Mazda C lamps is to divide the show-windows into classes from 1 to 10, class 1 including those in which the lowest standard of illumination is required and class 10 those of the largest stores and exclusive shops on brightly lighted streets. Classes 5 and 6 cover the average store. The rule is to add the depth of the window, in feet, to the height of the lamps above the window floor, in feet, and to multiply this sum by the class number of the window. The result represents the watts required per running foot of the show-window if Mazda C lamps are used. If Mazda C-2 lamps are used 50 per cent. more watts are required for approximately the same intensity of illumination. Although this rule will provide satisfactory intensities for the type of window considered, it appears best where conditions permit to provide three or four interwoven circuits of the character of the one determined by computation. The show-window is a stage and should be provided with outlets and circuits which make it possible to produce elaborate lighting-effects when they are desired.

The light-value of a skylight or window may be determined at any point by multiplying the area of the window through which the sky is visible by the brightness of the sky. This gives the available candlepower of the window considered from a given point and this is then divided by the square of the distance to the given point to obtain the foot-candle intensity of the illumination at that point. Obviously, this value will usually differ at various points in the room because of the variation in the amount of sky-area visible. This computation does not take direct sunlight into account and does not allow for the light reflected from the surroundings to the point under consideration. However, the minimum light-value of an opening is chiefly of interest and this will obtain when the sky is heavily overcast. A fair average sky-brightness may be taken as

[1] *Bulletin* 28, Engineering Department, National Lamp Works of General Electric Company.

approximately 1 lambert or 2 candles per square inch. On stormy days this will be reduced to a much lower value so that 0.5 candles per square inch is a minimum brightness which it is well to assume in such computations.

If a skylight is 18 feet above the "work-plane" and an intensity of illumination of 10 foot-candles is desired at a point on this plane the rough computation for the area of the skylight will be as follows, assuming a sky-brightness of 0.5 candles per square inch or 72 candles per square foot:

$$\frac{10 \times 18 \times 18}{72} = 45 \text{ square feet}$$

Inasmuch as this skylight is horizontal it is fair to assume that at all points on the work-plane, sky will be visible through the opening. In the case of diffusing glass the computation is more complicated but it will be conducted in the same manner after its brightness is estimated. This may be arrived at approximately through various considerations but a discussion of these is beyond the scope of this chapter.

In the foregoing the important rudiments of illumination computations have been discussed but in closing it is well to discuss the matter of brightness which is really the effect of illumination. The brightness of a surface depends not only upon the intensity of illumination but upon the reflection-factor and other physical characteristics of the surface. Brightness may be expressed in terms of luminous intensity per unit of area of the surface when the latter is perpendicular to the line of sight. When it is not perpendicular to this line, the area projected on such a plane must be considered. In the case of a perfectly diffusing surface the brightness is the same for any angle at which it is viewed provided other conditions remain constant. According to the definition, brightness may be expressed in terms of candles per square inch, per square foot, etc. A unit of brightness which is coming into use is the lambert which is the brightness of a perfectly diffusing surface radiating or reflecting 1 lumen per square centimeter. Although this unit has some advantages it is not always convenient to use in ordinary computations because it is a measure of

luminous output rather than of lumnious intensity. Furthermore, no perfectly diffusing surfaces exist and relatively few are found in practice which approach this ideal.

Brightness expressed in candles per square inch may be reduced to lamberts by multiplying by 0.4868.

A millilambert is one-thousandth of a lambert.

A lumen emitted by a square foot of a perfectly diffusing surface is responsible for a brightness of the surface of 1.076 millilambert.

One lambert equals 2.054 candles per square inch.

From these values it is easy to compute the brightness of a surface which is nearly perfectly diffusing provided the reflection-factor and the intensity of illumination of the surface are known. For example, if the surface were perfectly reflecting and diffusing each lumen incident on a square foot of area would be totally reflected and from the foregoing a brightness of 1.076 millilambert would result from each lumen reflected per square foot. However, a foot-candle is equal to 1 lumen incident per square foot so for an intensity of illumination of 10 foot-candles the brightness of this ideal surface would be 10.76 millilamberts. If the reflection-factor were 0.6 instead of unity, under this intensity of illumination its brightness would be 6.456 millilambert. This may be converted into other units of brightness by means of the data already presented. Unfortunately, these computations are based upon the special case of a perfectly diffusing surface. The ordinary case is difficult to compute and actually impossible unless the reflection characteristic curve of the surface is known, which is not usually the case.

CHAPTER XXIII

NATURAL LIGHTING

Although natural daylight is of great importance to the human race from the standpoint of lighting, it has received little consideration in this volume because it is of less direct importance to the lighting specialist than artificial light. Natural lighting does not possess the potentiality that artificial lighting does because it is generally less readily controlled and adapted to the problems. Furthermore, the architect has become well acquainted with the means for admitting daylight into interiors because of the influence of such openings upon the location and plans of a building and of the necessity for providing these openings during construction. In some classes of buildings, such as school buildings, modern office buildings and modern factories, the daylighting is being done perhaps as well as is practicable, however, the lighting specialist may often be a valuable aid to the architect.

It does not appear advisable to present a discussion of the engineering of natural lighting because of the lack of general interest of this aspect among lighting specialists; however, a broad view of lighting and its possibilities cannot be had without being familiar with the general characteristics of daylight. Therefore, it appears of interest to discuss natural lighting outdoors and indoors briefly.

Daylight is a very indefinite term, for the distribution, quality (spectral character), and intensity of daylight vary momentarily, daily, seasonally, and geographically. In fact, the most striking feature of daylight is its variability and, although this is often annoying, the lack of monotony is one of the attractive features of daylight. We may learn much from Nature regarding lighting and the lesson gained from its lack of monotony is to aim at variety in artistic lighting.

On a clear day there is a highly directed light from the sun

which varies in intensity from zero at sunrise to a maximum at noon and to zero again at sunset. Besides this there is the light from the sky which is directional to some extent but is considered highly diffused because of the large angular area of the sky. The intensity of skylight is close to zero at dawn but has arisen to a considerable value at sunrise and is fairly constant throughout a large portion of the day. The brightness of the sky, and consequently the intensity of skylight, depends upon atmospheric conditions. Add to these variables, the effects of moving clouds, of the different horizons as seen from various points outdoors and indoors, of the changing cloak of Nature and of many other factors and it is seen that daylight is extremely variable in distribution.

The quality or spectral character of daylight is also quite variable as is evidenced by the colors of sunrise and sunset and by the bluish color of the sky as compared with sunlight. The latter is very apparent to the careful observer for the shadows on a clear day are seen to be quite bluish in color compared with their sunlit surroundings. On overcast days the color of daylight is a mixture of sunlight and skylight quite similar to their mixture on a clear day, although certain atmospheric conditions appear to be responsible for changes in the spectral character of the light. There is a popular belief that noon sunlight is yellow in color but this is due largely to the effect of hue contrast. For example, white clouds viewed amid the surrounding blue of the sky appear to be quite yellow in color. However, if they are viewed through a small hole in a black card or dark box so that no surrounding blue sky is visible, they appear quite white.

It is well known that north rooms appear much "colder" in color than south rooms in this hemisphere and this fact is important in lighting. The coldness is usually overcome by the decorative scheme which is additional proof that the latter is closely interwoven with lighting. The hygienic value of sunlight is also recognized and therefore the location of certain rooms in school buildings, hospitals, homes, etc., should depend upon the orientation of the building.

The mixing of daylight and artificial light in interiors is an

important feature in lighting which involves both the distribution and color of the two illuminants.

The intensity of daylight illumination outdoors ranges from practically zero to as high as 10,000 foot-candles. On very clear days when the atmosphere has been freed from much of the solid matter which has been suspended, the entire hemisphere of sky contributes from 10 to 20 per cent. of the total light which reaches a horizontal surface. Obviously, the portion of the total light contributed by the sky at a given point on a clear day decreases with the angular extent of sky which is visible from the given point. These facts are of importance both from the standpoint of light and shade effects on objects and of the light-values of daylight openings into interiors. The brightnesses encountered outdoors are of an extremely greater magnitude than those found under artificial lighting conditions but the brightness-contrasts outdoors are usually less than those encountered indoors at night.

Nature's landscapes are really effects of light, shade and color, and inasmuch as there are an infinite number of lightings available, Nature provides a storehouse of studies for the lighting specialist who hopes to become familiar with the psychological or artistic aspects of lighting. It is interesting to note the changes which a given natural setting outdoors undergoes as the distribution and color of daylight varies. Nature not only provides a vast variety of lightings which may be studied profitably but it has been a powerful influence in the evolution of taste. One cannot note the general decorative scheme of interiors with their darker floors and walls and lighter ceilings without seeing the resemblance to Nature's landscapes. In the latter the brightnesses are ordinarily greatest in the sky. In other words, the foreground, middle distance and sky of a landscape are similar in arrangement of "values" to the most common decorative scheme employed in interiors. However, variety is a keynote in Nature's lighting which it is well to bear in mind in artificial lighting.

Among all the lighting lessons which Nature teaches there is the fundamental one—the rainbow—which is a demonstration on a huge scale that light ordinarily consists of many individual

rays of different wave-lengths which, when permitted to stimulate the visual organs separately, produce sensations of light differing in color. In other words, the rainbow is a natural decomposition of sunlight into its component rays. In the study of light and color a similar separation of the spectral colors is made by means of the prism or diffraction grating.

Few attempts have been made to modify the daylight which enters buildings but there appear to be possibilities in this direction. An incandescent source such as the sun emits radiant energy which when absorbed by a body is generally converted into heat. This is not always true; for example, much of the radiant energy from the sun which is absorbed by vegetation is converted into chemical action. Radiant energy is supposed to be propagated in the form of waves and such a source as the sun emits this kind of energy of many wave-lengths. Radiant energy of a certain range of wave-lengths is capable of exciting the sensation of light. The invisible rays of shorter wavelength than visible rays are called ultra-violet and the invisible rays of longer wave-length are termed infra-red.

Just as ordinary objects are more or less transparent to radiation of various wave-lengths (spectral colors) so are different objects more or less transparent to the various invisible rays. For example, water is quite transparent to the visible rays and is opaque to nearly all the infra-red rays. For this reason much of the infra-red radiation emitted by the sun is absorbed by the water vapor in the atmosphere. Similarly the extremely short ultra-violet energy which is emitted by the sun does not reach the earth although the spectrum of sunlight shows that considerable quantities of ultra-violet energy between 0.295μ and the visible spectrum (violet limit about 0.39μ) reach the earth.

There is much less energy associated with a lumen of sunlight than with the same quantity of artificial light owing to the absorption of much of the infra-red radiation by the atmosphere and to other reasons. However, owing to the enormous intensities of daylight illumination the actual amount of energy which reaches the earth's surface is great. If a glass could be made which would not transmit any infra-red rays it should be desir-

able in some cases for use in skylights. An approximation to this can be obtained.

The foregoing is well exemplified in a greenhouse covered with glass. Glass is opaque to some of the infra-red rays of long wave-lengths but it transmits the infra-red rays of shorter wave-lengths. After the radiant energy enters the greenhouse through the glass some of it is absorbed and changed into heat energy. This results in heating the object which absorbs it and the object now acts as a radiator similar to the sun but of a very much lower temperature. Nevertheless it emits radiant energy but having a low temperature the radiation is all of very long wave-lengths. This energy cannot escape through the glass and is therefore trapped and must expend itself largely as heat; hence the interior of such a glass-covered house becomes appreciably hotter than the surroundings. There are many other interesting details but the foregoing may give an idea of an effect which is of interest to lighting specialists.

Rooms of northern exposure are often made more cheerful by using hangings and shades having a warm yellowish tint. It appears that this idea might be carried further for the psychological effect upon the occupants of an interior. For example, the north rooms in an office building are not cheerful and inviting for a large part of the year owing to the coldness of the light. It is not generally practicable to overcome this entirely by window hangings and decorations. However, it is possible to make a window-glass of a slight yellowish tint (a warm tint, not amber) and this could be installed permanently in the north windows. The author has tried this on a small scale and the effect is extremely pleasing. In this manner the north rooms of art museums and other interiors could be made as inviting as the other rooms.

Although natural lighting is full of interest outdoors it does not enjoy the highest favor in interiors because it is difficult to control. Furthermore, it loses much of its variety indoors and that which it still possesses is usually the undesirable variety in intensity which makes it undependable. It is often stated that one of the great virtues of daylight is that it is free, but this is not true indoors. The constructional cost of windows

and roof skylights is usually greater than for ordinary walls and roofs and sometimes this cost is much greater. Light-courts are installed at the sacrifice of ground and floor areas, which is a costly item in cities. Windows sometimes occupy valuable wall areas and there is a maintenance cost which is appreciable. Furthermore, architects appreciate the excessive radiation of heat by glass and consequently allow an additional capacity in the heating system depending upon the area of glass exposed to the weather. On combining these cost data with the disadvantages of daylight from the standpoints of control and dependability, it is seen that it is possible for artificial light to compete with natural light in some interiors today and perhaps in many interiors in the future.

The dominant direction of daylight in most interiors is usually oblique and from one or two sides. This is quite different from the usual dominant direction of artificial light. The ideal illumination in many work-rooms which are used after dark would be to have the distribution of the natural and artificial light approximately the same provided this can be done without making a sacrifice in either case. Many interesting facts may be gleaned from a study of the distribution of natural light in interiors, preferably by measurements, but much of value may be gained by observation. The relative amount of diffused light is usually greater in interiors illuminated by natural light than by artificial light; that is, the shadows are usually more luminous. From this standpoint, indirect lighting is usually comparable with natural lighting; however, this system of lighting more nearly simulates the distribution of light outdoors on an overcast day than any other distribution of daylight.[1] It is an interesting experiment to simulate the distribution of daylight in an interior by means of dummy windows illuminated by artificial light. The utilization efficiency of rooms illuminated by daylight entering windows was found in three cases which were investigated to be from 17 to 33 per cent. That is, these are the percentages of the total lumens entering the windows which were effective on the ordinary horizontal

[1] M. Luckiesh: "Natural and Artificial Light-distribution in Interiors," *Trans.* I. E. S., **7**, 388, 1912.

work-plane. Observations along this line yield much interesting data and at least stimulate thoughts which lead the lighting specialist out of the ruts of common procedure. Many interesting details could be discussed but the aim has been to awaken an interest among lighting specialists with the hope that they will make such observations and analyses in order to become more intimately acquainted with lighting.

Although it is difficult to control daylight and this may seldom be done with the satisfactoriness with which artificial light is controlled, there are various means which are helpful aids. There is available an extensive variety of glasses such as sandblasted, etched, opal, ribbed, pebbled, and "refractive" from which the most suitable may be selected. However, a proper selection will depend upon a knowledge of simple optical laws and upon the many details of a specific condition. There are many designs of prism glass available and the proper selection and installation for a specific case must depend upon judgment backed by a knowledge of the simple optical laws. Shades shutters, and louvers are also valuable accessories in natural lighting. Even the painting of surfaces of light-courts, walls of adjacent buildings, and the surroundings in interiors is an important aspect in natural lighting. In fact, owing to the usual handicap of the location of windows in the walls, the best results in distributing daylight in interiors will be obtained only through exercising much ingenuity. Some of the redeeming features of natural lighting are the usual excessive quantity available, the adaptation of the eyes to a high level of illumination, the low brightness of the source which is generally the sky, and the amount of diffused light.

CHAPTER XXIV

THE LANGUAGE OF COLOR

In mythology the fact is revealed that color has impressed mankind long before the beginning of written history and from a study of the primitive races of today it appears safe to conclude that the influence of color upon the human organism began in an early stage of the evolution of man. There is a degree of consistency in certain psycho-physiological effects of a few fundamental colors which warrants the formulation of the title of this chapter. Owing to these effects it may be said that, at the present time, colors possess certain innate powers or attributes which affect the human organism without the necessity for an accompanying associational mental process. How this influence has developed is of scientific interest but it need not be discussed here. However, it can be shown how certain agencies such as Nature, the consistent and persistent usage of colors in ecclesiasticism, in painting, in the theatre, and in many activities in daily life, the interpretations of poets and mental associations have welded certain attributes to various colors with the result that we have a meager though definite language of color.

But it should be emphasized that our definite knowledge of the expressiveness and impressiveness of color is extremely limited and that the effusions on this subject by those who possess at best only a superficial acquaintence with the intricate fabric of color-science are mixtures of fact and fancy with a superabundance of the latter. However, the earnest student of this subject finds sufficient definite and consistent data in various indirectly associated fields to encourage further exploration, study and experiment which may aid in a more scientific use of color. Color is a medium capable of creating pleasure and this should be a sufficient stimulus to the lighting specialist to inspire him to attempt to utilize its power in lighting. To those who have opened their eyes to the fact

that lighting should be considered more from the psychological than from the engineering standpoint in nearly all aspects of the field, no plea for utilizing color in light is necessary.

A great difficulty is encountered in the use of color in lighting, which is equally true of many other activities; namely, in recognizing the boundary between fact and fancy or between the psycho-physiological effects upon mankind as a whole and that which we call taste. Taste is individualistic and largely a personal right; therefore it may be said to be indeterminate. Although individual taste should be respected, it is not necessary to such an extent that some of the generalities of esthetics are permitted to be violated. However, there are certain fundamental effects of various colors upon the human organism regardless of personality and these the lighting specialist may utilize as a foundation for any attempt at utilizing color in lighting for its psycho-physiological influence or for its decorative and artistic effect. Only this meager basis may be used generally for when the personality of a client enters it should be remembered that the effects of colors will depend upon the individual owing to the influences of intellectual development, experiences and temperament of the individual.

Owing to the indefiniteness of the language of color it is impossible to discuss it completely in a brief chapter because of the necessity for so much qualifying material; however, it appears of value to touch upon the subject for whatever the material which is presented may be worth and as a sort of prophetic valedictory. At least it may be of value in inciting thought and observation along a line which will be profitable to the lighting specialist who may be thus encouraged or inspired. The subject may be readily studied by making observations on every hand and by delving into such fields as mythology, ecclesiasticism, poetry, painting, decoration, architecture, Nature, the theatre, and various symbolic uses of color in daily practice. A volume has been prepared[1] which aims to present the data gleaned from these and other sources. Portions of Chapter IX may be considered as prefatory to the present discussion.

[1] M. Luckiesh: The Language of Color (in press).

In order not to be led too far afield only a few of the most conspicuous colors will be treated. Space will not permit going far into detail but it should be noted that such factors as associations and usage are important influences in molding the meager language of color which is available today. Furthermore, a color may possess many attributes depending upon its environment, its saturation or purity, the association which it arouses owing to its particular use, the occasion, etc. From a consideration of these factors and encouraged by the definiteness of the data given, it is hoped the lighting specialist will find it easy to extend his horizon regarding this interesting and potential, though uncultivated, aspect of lighting. Aside from this broader view of the use of color in lighting there are purely utilitarian uses which may be directed more or less by the facts of the symbolic usage of color. All of these cannot be presented but the few that are given should inspire a more consistent and general utilitarian usage of colored light. In many applications of colored light the decorative scheme must be controlled and even called upon to aid in carrying out the desired effect.

Red is universally considered to be stimulating or exciting and this has been proved by experiment. The nerves are in an excited state and it has been shown that the amount of certain kinds of work which can be done in a given period of time is augmented under red light. Its effect is similar to that of other stimulants in this respect and its continued use would be as readily condemned. In the lighter tints it becomes mildly stimulating and rose, which is a tint of a reddish-purple, is delightfully stimulating in a mild manner. For this reason light of a barely perceptible rose tint—more felt than seen—is appropriate for living and dining rooms on certain occasions and in ballrooms, restaurants, etc. Light tints of red and even red combined with white have been used symbolically to suggest blooming youth, health, and happiness.

Perhaps the most general association which is coupled with red is blood. For this reason it has been endowed with appropriate attributes in poetry, mythology, etc. It has been the flag of war and has ornamented the shield of tried manhood, being the badge of valor, superiority and prowess.

Perhaps its most general utilitarian use is as a signal of danger and this is an excellent example of the influence of persistent usage for in its proper environment red is always recognized as indicating danger. It is perhaps the most striking color and apparently is the first to be named by the savage as he begins to ascend the ladder of intelligence.

It shares with blue the highest rank in the scale of preference when this is based upon color uninfluenced by associations as completely as possible. There is strong evidence that it is more preferred by females than any other color. These conclusions are based upon scientific experiments in which the proper control of various factors has been exercised as far as possible.

Yellow in its warmer hues and orange possess the same stimulating characteristic as red though of a milder degree. It is interesting in this respect to note that shades and tints of yellow are used predominantly in decorating interiors. Perhaps this has arisen from the psychological effect of this color which imparts warmth to an interior and logically it is one of the aims in housing to provide a cheerful, inviting, and protective environment. Of further interest in lighting is the warm yellowish tint of nearly all the early illuminants which through the persistence of habit have added their influence in creating the desire for illuminants of a warm color in interiors. These may be obtained by means of tinted lamps, screens and glassware and the same effect may be obtained by indirect systems of lighting in rooms whose walls and ceiling are yellowish in hue. The finer color-sensibility manifests itself in an aversion toward amber—a greenish-yellow—which is sometimes considered by the uninitiated to be a substitute for warm yellow.

Yellow is a luminous color and is often associated with sunlight although strictly the latter is not yellow except during sunrise and sunset. However, it appears yellowish by contrast with blue skylight. Being warm, luminous, and associated with the sun, yellow has been symbolic of fire.

The attribute of abundance has been bestowed upon yellow doubtless through association in Nature with the bountiful harvest because this is a common color of ripened crops.

This color has been widely used by poets to symbolize jeal-

ousy but usually a greenish-yellow is described or implied. It has also been used to symbolize inconstancy and deceit though in this office an impure or soiled yellow is usually implied. For example, the garb of Judas is often described as being of a dirty yellow and the custom has been in vogue in past centuries of using yellow on the doors of the abodes of felons.

It has been quite generally used to symbolize sickness; hence it is the flag of quarantine and has been used to indicate field hospitals in war.

Green is most characteristically described as being a neutral color. Perhaps its abundance in Nature has gradually subdued any striking influence it might have had on the human organism and doubtless continued adaptation to this color in natural environments has rendered it neutral. There is no doubt about this characteristic and hence shades and tints of green are proper colors for certain interiors. The applications of green light, however, appear to be extremely limited although scientific investigation may indicate certain desirable psycho-physiological effects which may be utilized in the future. It has a place in lighting as a vital or contrasting spark in certain attempts which may be made to "paint" with light. It is used to symbolize perpetuity as "evergreen memory" and the practice of placing green foliage upon the graves of the dead is one of fine sentiment. Doubtless, due to the fact that green is the conspicuous color of springtime, this color is used to symbolize youth, immature judgment, vigor, freshness, and hope.

Blue is a cold color, the degree depending upon its exact hue and purity. When it inclines toward violet it appears to lose this attribute and to become restful. Blue is of low luminosity and being cold is somewhat depressing when used in lighting. However, it may be used to advantage sometimes when it inclines in hue toward green. For example, a theatre in mid-summer seems to be much more comfortable when illuminated by blue or blue-green light. It is thus seen that an attribute of a color which ordinarily may be unpopular, can be used to advantage in a proper place. Many such applications of colored light fall within the province of the lighting specialist.

Certain tints and hues of blue appear to possess the attribute

of serenity, at least this has been bestowed upon them. This may arise through the restfulness of these colors but it is interesting to note that the finer sensibilities have recognized the serenity of the blue sky and of Nature's solitudes. In the latter case the illumination often is chiefly due the blue skylight. Owing to the dominating presence of blue sky in natural scenes this color has also been looked upon as possessing a harmonizing influence because in Nature it is a color which is nearly always present in any scene.

Perhaps owing to the fact that it is the color of the heavens—the abode of the Gods—mythology has also bestowed upon this color the attribute of intelligence. Many interesting speculations arise in the study of the language and symbolism of color. For example, blue eyes are very common and the eyes are closely associated with the intellect and personality. From these reasons the attribute of intelligence may have partly arisen or Minerva may have been considered the "blue-eyed" progeny of Jove for similar reasons.

As blue inclines toward violet or toward a deep shade (corresponding to a lower intensity when applied to light) it has been characterized as restful, quiet, dejected and even dismal. It is easy to account for these attributes partially through our experiences with Nature.

Purple has scanty application in lighting though it appears to be characterized by certain attributes and symbolic uses. It has been chiefly characterized as dignified, stately, sedate, solemn, and pompous and has long been the garb of royalty. The latter is another example of the influence of usage for doubtless it became the color of royal robes because in the early centuries of civilization it was a rare and costly color. For this reason it became the mark of royalty and wealth. It is sometimes used in mythology and poetry as the color of blood which is a more correct usage than red for the same purpose; therefore, it was used symbolically in appropriate ways. Rose, a tint of purple, has already been discussed.

White naturally assumed the attributes of chastity, virginity, purity, innocence, fidelity, peace and friendship; and mythology and poetry abound with examples of such usage.

It also symbolizes weakness perhaps through association with femininity and was the mark of untried manhood. Consistently therefore it is appropriately the flag of surrender and of truce.

Black naturally is quite opposite in character to white, being characterized as dismal, desolate, deadly, malignant, threatening, evil, chaotic and loathesome. Its symbolic uses are very numerous and consistent as is true of white. It is evident why it is almost universally used in mourning and in various other ways. It has its place in lighting-effects for low intensity of illumination or the absence of light in the proper places in an interior is a potent factor in lighting-effects.

Many other colors and combinations of colors appear to have symbolic uses or attributes seemingly appropriate. For example, gray which lies between white and black partakes of the attributes of both and by this mixture or balance assumes a rôle lying conspicuously between them. Attributes are bestowed upon it which are quite the same as those bestowed upon black and white when used together. In fact, the whole fabric of the language of color as obtained from many different sources appears to be solidly interwoven, but there are so many aspects that it is easy to go astray in examining it.

Much of the information gained from a study of this character may be applied only indirectly; however, it is valuable to the lighting specialist for it deals with color and therefore with light. Lights of all colors have at least decorative value and must be applied in this respect according to the principles of harmony.

There are no laws of harmony which can be stated in a few words because such a statement resolves into a description of a single harmony. However, it may be noted that in dealing with colors there is the principle harmony of sequence and that of contrast. According to the former the hues of the colors used are closely associated in the spectrum or a sequence of approximately the same hue is arranged in respect to tint or shade. According to the principle of harmony of contrast the colors are contrasting, or far apart in hue.

It is confidently predicted that the aspect of color considered in this closing chapter will be an important one in lighting

at some future time for it represents the climax of the expressiveness of light. Therefore it is the logical climax of an attempt to present a broad view of lighting in so far as the space of a brief volume permits. It is hoped that some of the material presented in these chapters will be of immediate value; that some of it will suggest new ideas; and that the whole has revealed, to a small degree at least, the potentiality of light and lighting.

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